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EARTH OBSERVATORY SATELLITE SYSTEM DEFINITION STUDY

REPORT NO. 3: DESIGN/COST TRADEOFF STUDIES

- Appendix E: EOS Program Supporting System Trade Data
- Part 2: System Trade Studies No. 9 through 19

(NASA-CR-143669) EARTH OBSERVATORY SATELLITE SYSTEM DEFINITION STUDY. REPORT NO. 3: DESIGN/COST TRADEOFF STUDIES. APPENDIX E: EOS PROGRAM SUPPORTING SYSTEM TRADE DATA. PART 2: SYSTEM TRADE (Grumman G3/18 N75-15715 Unclas 09252

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EARTH OBSERVATORY SATELLITE SYSTEM DEFINITION STUDY

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Prepared For

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*System Trade Study No.

INTERNATIONAL DATA ACQUISITION

1.0 INTRODUCTION AND SUMMARY

The primary objectives of this study are to establish the relative merits of several international data acquisition (IDA) alternatives for EOS and to rate these alternatives on a cost-effectiveness basis. The primary alternatives under consideration are:

Option 1: Direct transmission (D.T.) to foreign user ground stations

Option 2: A wideband video tape recorder (WBVTR) system for collection of foreign data and processing and distribution from CONUS.

Option 3: A TDRSS configuration for the relay of foreign data to CONUS for processing and distribution.

A requirements model is established for this analysis on the basis of the heaviest concentration of agricultural areas around the world. This model, the orbit path and constraints of EOS and data volume summaries are presented in Paragraph 2. Alternative system descriptions and costs are given in Paragraph 3 and system cost-performance summaries presented in Paragraph 4. Conclusions and recommendations of the study are in Paragraph 5.

In summary, this study establishes a quantitative measure of the relative cost-effectiveness of IDA alternative configurations and their technical risks for the EOS program. A hybrid configuration of the D.T. and WBVTR options is demonstrated to be a low risk and cost-effective option for low volume data missions while the TDRSS configuration is the most cost-effective for large data volume scenarios but with attendant technical risks. The senstivity of the TDRSS costs to the particular manner in which costs are proportioned between system users is also demonstrated. This impacts the cost-effectiveness rating of the TDRSS approach and together with this option's technical risks forms the basis of a recommended lower risk IDA hybrid system configuration.

2.0 REQUIREMENTS MODEL

2.1 AREAS OF THE WORLD AND USER NEEDS

The requirements model employed in this analysis assumes that the land areas of greatest interest are those that coincide with the heaviest concentration of agricultural areas. These areas include the continents of Australia, South America, Asia (Including USSR), Africa and Europe. Great potential benefit can be derived to the remote sensing users in these and adjacent areas if thematic mapping or high resolution image data could be provided to monitor crop growth, disease and insect problems and irrigation status information. Furthermore since little tilled land in the world lies north of latitude 60°N or south of latitude 60°S; primary attention is in the mid-belt zone of the world between those latitudes. Finally, the coverage required to include one major crop, such as wheat, places a lower bound on the data analysis volume of interest.

The International Data Acquisition (IDA) analysis has therefore concentrated on three levels of data volume or coverage. The first coincides with the complete coverage of these five land areas; the second the areas lying within the tilled land belt and the third the subset of these areas containing the major concentration of wheat.

2.2 EARTH TERMINAL LOCATIONS AND COVERAGE

In order to provide the coverage necessary for the areas of the world cited above using the direct readout option for the EOS data to foreign users, it is necessary to locate ground stations at strategic places in or adjacent to the areas of interest. For this analysis seven regional ground stations have been used with the following locations and minimum elevation angles of observation:

Australia

Darwin - 5°

South America

Caracus - 5°

Santiago - 5°

Turkey

Ankara - 5°

Spain

Madrid - 5°

Africa

Johannesburg - 5°

India

Bombay - 5°

These locations were selected on the basis of adequacy of land area coverage with minimum overlap of station patterns.

The CONUS sites of interest for WBVTR data dumps of option 2 are:

Alaska - 5°

NTTF - 5°

Goldstone - 5°

A precise description of the exact role of each location in the IDA analysis will be provided in subsequent sections, however, each of these locations has been examined in the analysis.

2.3 ORBITAL DATA AND PATH CONSTRAINTS

Figure 1 illustrates a typical day's orbits for the EOS, the location and coverage patterns of the three CONUS stations and the location of foreign user stations employed in the IDA analysis. When regional stations were assumed in the analysis at foreign user loactions, 5° elevation coverage patterns similar to those in CONUS were employed; low cost ground stations (LCGS) at foreign user locations employed a 30° elevation coverage pattern.

EOS orbital data of interest includes:

- Altitude 678.01 KM
- Period 98.31 minutes
- Inclination 98.09°
- Complete orbit cycle 17 days
- Orbits/day 14.65
- Orbit change/day 8.6°
- Orbit separation at equator 24.67°
- 3 day revisit cycle
  - 86.9 NM separation of adjacent swaths with 13.13% overlap
- Ascending phases correspond to night time; descending phases to day light.

In order to quantitatively evaluate the performance of the three primary alternative methods of providing image data to foreign users, a detailed analysis of three separate days orbits was conducted. The orbital days analyzed corresponded to the first, the third and the two-thirds interval of the basic 17 day orbital cycle of EOS. The total available time (in minutes) over each land area was calculated for each of the orbital periods and then compared to the data availability time provided by each of the three

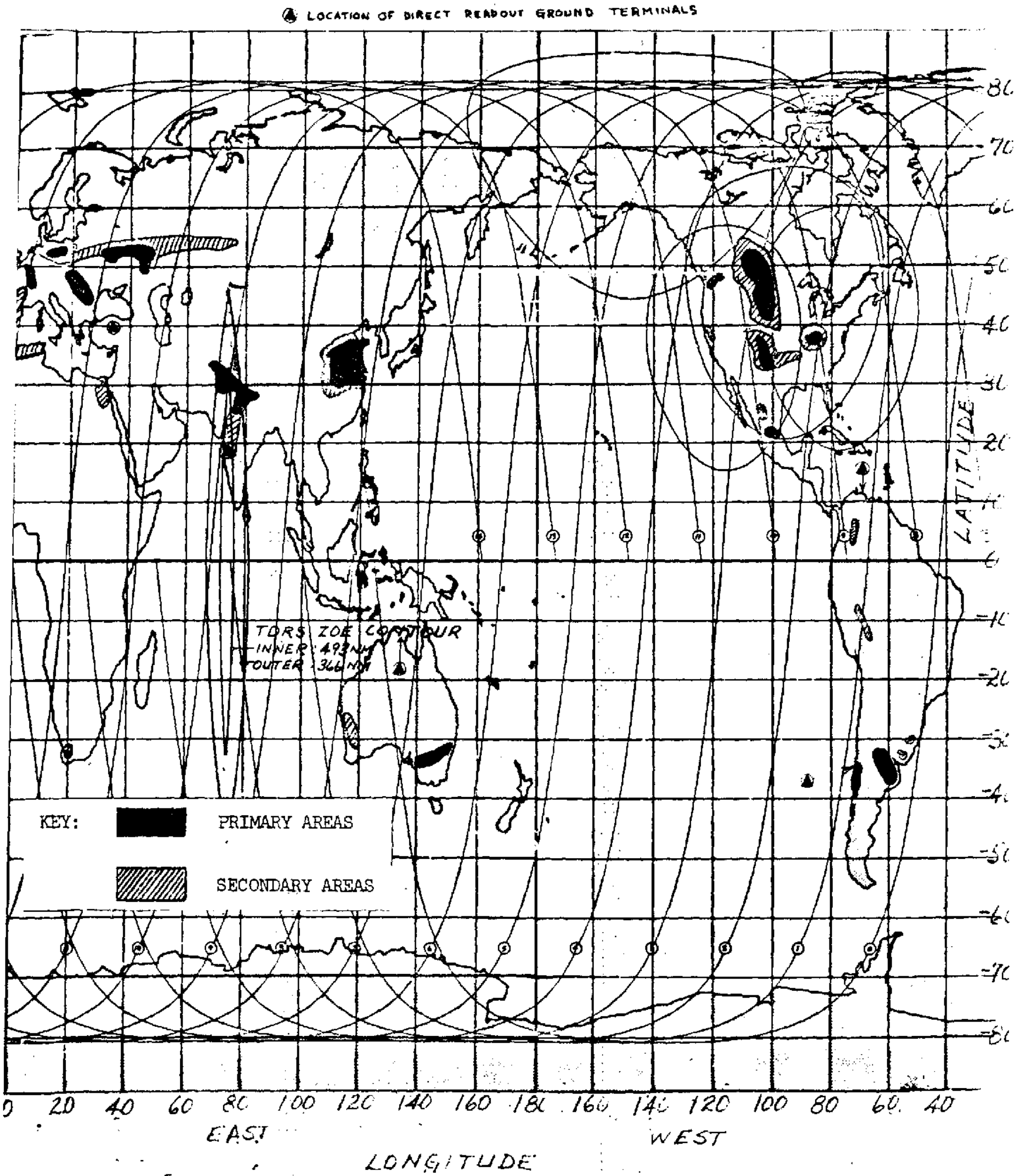

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Fig. 1 Approximate Wheat Growing Areas of the World

alternatives; direct transmission, WBVTR and TDRSS. The time the EOS spends between various latitudes on its orbit and the distance covered in this interval is given in Table 1. These data were used in conjunction with Figure 1 to determine the appropriate time availabilities of interest.

Latitude Interval	Time Spent (minutes)	Distance (N. M.)
Zenith - 70°	4.75	1000
70 - 60°	3.25	675
60 - 50°	2.75	625
50 - 40°	2.75	600
40 - 30°	2.75	575
30 - 20°	2.75	575
20 - 10°	2.75	575
10 - 0°	2.75	575

Table 1. EOS Latitude-Time Data

2.5.1 Path and Alternative Constraints

For the direct transmission (D. T.) alternative, the primary constraint on data availability is the coverage provided by the assumed foreign site ground station locations and elevation angles. Assuming that each of the seven foreign sites listed in Paragraph 2.2 is occupied by a regional station with 5° elevation angle, a substantial percentage of the land masses of interest will be in view of the stations. Only land masses at the higher latitudes and/or in the countries of Asia and USSR will not be in view of these sites.

For the wideband video tape recorder (WBVTR) alternative the percentage coverage is limited by two primary factors:

1. The tape recorder capacity limits, i.e., 13 minutes of data at 200 Mbps;

2. The necessity of dumping data at a site that is in view on the same orbit in which data was collected or paying the penalty of additional storage if successive orbits pass before a data dump opportunity arises. For this analysis only the Alaskan and Goddard sites were used as WBVTR dump sites and a day light recording pass over the land areas of interest was assumed. The data dump periods were not constrained to occur only at night time although this has potential impacts on the scheduling and processing loads at NTTF.

The TDRSS alternative provides the capability of 100% coverage of all areas of interest with the exception of a small zone of exclusion (ZOE) that results when neither of the two TDRSS satellites is in view of the 678 Km EOS. This ZOE is shown in Figure 1.

2.3.2 Typical Orbit Cases

In order to illustrate the analysis methods and procedures used in this study, typical orbit calculations will be presented in this paragraph. Consider orbit No. 7 shown in Figure 1; this orbit begins at 335° latitude at the equator and terminates at 50°W latitude; accounting for the following data availability times along its orbit:

USSR	6 minutes, day light
Australia	5.5 minutes, day light
South America	6.86 minutes, night time
Africa	0 minutes
Europe	0 minutes

Of these available data times, regional ground stations at the direct transmission sites would be capable of observing the following times:

Australian Terminal (5°)	5.5 minutes (100% of time available over country)
South American Terminals	
Santiago (5°)	0 minutes (0% of time available over country)
Caracus (5°)	1.2 minutes (17.5% of time available over country)
Alaskan Terminals (5°)	3 minutes (50% of time available over USSR)

The Alaskan site also provides the opportunity for 8 minutes of WBVTR data dump on this pass. Note that in this case the 8 minute pass for tape recorder data dump is in day light but the orbit carries the satellite over water for most of the coverage time. This last factor influences the desirability of this orbit for data dump since while the satellite is over water, there is less likelihood that direct readout of other data would be scheduled for that pass over Alaska.

The data availability times for this and other orbits can be obtained from the EOS latitude-time table (Table 1) presented in Paragraph 2.3 and observations of the orbit ground track over the various land masses given in Figure 1. D.T. data availability times are computed in a similar fashion but in this case only the orbital ground track that is within the coverage pattern of the site is counted.

WBVTR data dump time can be ascertained from a coverage analysis of either the Alaskan or NTTF (Goddard) sites on an orbit by orbit basis. However, in this case only orbital data collected from a preceding orbit is normally available for readout from the tape recorder.

The analysis of succeeding day's passes can be conducted by sliding the orbits shown in Figure 1 to the west 8.6° per day and repeating the same pattern of orbit tracing for that day's (14) orbits. When this procedure was followed for all of the orbits examined in this study, several significant results were obtained that impacted the WBVTR alternative results. First for this alternative to be viable for data analysis collected over both Eastern and Western Europe, a minimum of 5 orbit periods elapses before that data can be dumped at Alaska. On the other hand, if the Goddard site is used as a data dump site only 1 to 2 orbit periods elapse for the Western Europe data and 2 to 3 orbit periods for the Eastern Europe data. Second, South American data collected on any orbit pass can be dumped on the next orbit (the manner in which orbits are numbered in Figure 1 dictates this observation) for the Goddard site but cannot be dumped at Alaska without storage for between 2 to 3 orbit periods. These results have a significant impact on the percentage of available data provided by the WBVTR alternative, the storage requirements for the spacecraft tape recorder or number of WBVTRs carried and the desirability of having at least two sites (Goddard and Alaska) at which data collected over these land masses can be dumped. Finally without the WBVTR alternative IDA configuration large percentages of land areas or equivalently data availability time would be lost due to the nonavailability of D. T. terminals over the Asian USSR continent and precludes the possibility of reducing D. T. system costs by providing partial coverage of critical agricultural areas using the WBVTR alternative in conjunction with D. T. terminal readout over more easily accessable land areas. This latter hybrid (combination of D. T. and WBVTR alternatives) configuration will be discussed further in subsequent paragraphs.

2.4 ORBITAL DATA ANALYSIS SUMMARY

The results of the orbital analyses described in the preceding paragraph are summarized in Table 2. The land areas of interest in this study are given in the first column. For each of these areas, the following statistics were calculated; the average orbit pass duration, the total orbit time over that area for all orbits analyzed (3 days), the total data time available for the direct transmission alternative and the corresponding data time available with the WBVTR alternative, for both an Alaskan readout only and an Alaska plus Goddard readout station cases. An indication is also given, in column 4, of the relative fraction of the D. T. time at each site for a given land area. It should be noted that the Indian site yielded very little coverage, percentage use, for the total land areas of interest and could be dropped from consideration without affecting the statistical significance of the relative performance merits of the alternative IDA configurations. This site's contribution has not been included in the total time summary given at the bottom of Table 2.

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Table 2. Orbit Data Summary for IDA

Land Area	Average Pass Time (minutes)	Orbit Time Available (minutes)	D.T. Time (minutes)	WBVTR Time (minutes) Alaska	WBVTR Time (minutes) Alaska & Goddard
Australia	5.14	20.55	20.55 (Australian Site)	17.8	17.8 + ΔT = 2.7 (rel to Alaska)
South America	9.83	59.6	50.[illegible] (1/3 Caracus) (2/3 Santiago)	0 (next orbit) *2-3 passes to dump data	47.3 (next orbit)
USSR/Asia	7.29	124	23.[illegible] (1/2 Alaska) (1/2 India & Ankara)	111.6	-
Africa	10.69	85.5	52.7 (1/2 Madrid & Ankara) (1/2 Johannesburg)	21.25	-
E. Europe	8.75	17.5	14 (Ankara)	** 5 passes storage	** 2-3 passes storage
W. Europe	7.57	22.7	12.8 (Madrid)	*** 5 passes storage	*** 1-2 passes storage

*'s - Indicate spacecraft storage problems if data is to be dumped at this site.

Totals:					
1. Land Areas: (avg. load/day)	(all areas given above) 329.85 (110)	174.65 (53%)	150.65 (45.7%)	200.65 (61%)
2. Tilled Lands	(excluding N & S of 60°) 267	174.65 (65%)	(56%)	75%
3. Wheat Crop	(foreign only) 70	64 (91.5%)	59 (84%)	61 (87%)
4. TDRSS-TOE	297 (90%) all land areas, 98% tilled land and 96% wheat crop			

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The total times given are indicative of the overall orbit time for all land areas given in column one, the total time over tilled lands in these same areas (those lying between 60°N and S) and the time over the major wheat areas outside of CONUS. Each of the alternative IDA configurations yields the percentage of these total available times that is listed in succeeding columns of the table. For example, the D. T. system gives 174.65 minutes or 53% of the total orbit time over all land areas, the WBVTR alternative gives 45.7% and 61% respectively, depending on whether the data dump site location is restricted to Alaska or includes both Alaska and Goddard. In the case of the WBVTR results, only data that could be dumped on the next orbit (following collection) was considered in the calculation of the data availability times for these options. If attention is confined to the relative performance over tilled land areas, the respective percentages of available time for the D. T. and WBVTR (both sites) configurations are 65 and 75% respectively. The foreign wheat crop results are shown in the last row of the total results summary and are not significantly different for any of the configurations. Finally, with a TDRSS configuration, virtually all of the total land area considered is available with the exception of the zone of exclusion region shown in Figure 1. The TDRSS configuration is therefore capable of yielding 90% of the total available time for land area data, 98% of the tilled land area and 96% of the wheat crop data time.

The relative performance rating of each IDA configuration is shown in Table 3 based solely on the percentage of available time each provides. The TDRSS configuration is clearly superior to the other configurations followed by the 2 site-WBVTR configuration, the D. T. system and finally the single site WBVTR system.

The results for the wheat crop data are not felt to be statistically significant since all configurations give a sizeable percentage of the total available time and with both the D. T. and TDRSS configurations the missing areas cannot be recovered due to the inherent holes in the coverage patterns of either of these systems.

Configuration Rating	Percent All Land	Percent Tilled Land	Percent Wheat Crop
TDRSS	1 (90%)	1 (98%)	1 (96%)
WBVTR 2 sites	2 (61%)	2 (75%)	3 (87%)
D. T.	3 (53%)	3 (65%)	2 (91.5%)
WBVTR 1 site	4 (45.7%)	4 (56%)	4 (84%)

Table 3. IDA System Performance Ratings

The only system capable of providing data on all wheat crop locations is the WBVTR configuration and for the European wheat areas, this coverage requires significant spacecraft storage since the data cannot be dumped on the next orbit pass following collection.

Although the statistical results presented allow a quantitative comparison of the relative merits of each IDA configuration, additional factors must be assessed in order to properly judge the potential benefits and disadvantages of any one system configuration. The WBVTR configuration, particularly if only one dump site at Alaska is assumed, implies significant storage onboard the spacecraft to collect most of the European and South American agricultural data. In lieu of requiring 3 or 5 tape recorders on the EOS, the collection of the data in this area would preclude the use of the tape recorder over other areas until the dump site became visible to EOS. As indicated in Table 2, this implies between 2-5 orbit periods for which no further data collection would be possible. An alternative to requiring additional storage on the spacecraft is to accept the 2-5 orbit period delay before this data is available over a CONUS data dump location. This may be an acceptable operational procedure in cases where only a low volume of foreign data is collected and there is no critical need for real time(next orbit) processing. Wheat crop data collection is an example of one mission where this may be an acceptable alternative.

The D.T. system results are obviously sensitive to both the number and coverage pattern of the foreign ground terminal sites. The results obtained in this analysis employed six (excluding the Indian site) sites with a 5° elevation coverage pattern. Even with this configuration approximately one half the land area data of interest was not available due to either site location limitations (noticeably in Asia/USSR) or coverage pattern holes.

Although the TDRSS configuration provides the highest percentage of data and does not suffer from the problems inherent with either the TR or DT systems, it too has inherent coverage holes (ZOE) and its cost must be assessed to obtain its true cost-benefit rating.

With any of these configurations the average daily load of 110 minutes of data, which converts to approximately 240 scenes of TM or HRPI imagery information, implies a sizeable processing load to any data reduction facility.

A hybrid system consisting of a combination of the D.T. and WBVTR configurations is an attractive alternative. Such a configuration could allow the coverage problems of the D.T. system to be augmented by the TR and reduce the storage and/or orbit outage time due to the WBVTR capacity and visibility limitations over Europe and South America by foreign site placement in these areas.

Final conclusions concerning the best alternative system configuration depend on the costs to provide the coverage performance demonstrated in this study. These costs figures will be presented in the following paragraphs and final conclusions and recommendations given on the basis of best cost-benefit or cost-effectiveness ratings.

SECTION 3 - ALTERNATIVE SYSTEM DESCRIPTIONS

A number of methods of providing transmission of imagery data acquired from the EOS mission to foreign users have been considered. These methods, alternatives and costs are discussed in the following paragraphs.

3.1 DIRECT TRANSMISSION SYSTEM

For this mission option, data would be acquired by the EOS sensors (HRPI and TM) while over the desired foreign user area and would be transmitted without delay from the spacecraft to a foreign user ground station. Transmission will be at X-band utilizing the same spacecraft equipments used for transmission of data to STDN sites or Low Cost Ground Station sites. It is assumed that the same two data rates will be used, 240 Mbps and 20 Mbps depending on the capability and requirements of the ground stations. It is estimated that approximately 6 regional ground stations and perhaps as many as 50 LCGSs would be employed.

The primary impact on the overall EOS program to provide the direct data transmission capability is in the area of the additional programming and scheduling required to facilitate the data dumps.

3.1.1 Spacecraft System Description

The spacecraft communications subsystem required to enable direct transmission of data to foreign users is essentially the same as that required for the EOS CONUS mission. This consists of two X-band communications subsystems including modulators, antennas, up-converters and RF output devices. The baseline subsystem chosen consists of a 4 watt output transmitter, a QPSK modulator and a steerable 1.6 ft. diameter antenna for the wideband 240 Mbps link. For the 20 Mbps LCGS link, a 40 watt output X-band transmitter, an earth coverage antenna and a BPSK modulator will be used.

A block diagram of the baseline spacecraft communications subsystem is shown in Figure 3-1.

3.1.2 Ground Terminal Description

The individual foreign user ground terminals will be provided, operated and maintained by the particular user or area requiring coverage. The primary regional ground terminals will be designed to receive the high data rate downlink signal and in conjunction with the baseline spacecraft communications subsystem design provides an E_b/N_o of 12 dB for a bit error rate of 10^{-5}. Sufficient link margin exists to allow reduction in the size of the ground antenna from the 30 ft. used at the STDN sites. It is found that a ground antenna of approximately 18 ft. diameter provides sufficient margin to meet the system requirements depending on the desired minimum elevation angle. An 18-ft. X-band tracking antenna and pedestal will therefore be required at each regional ground terminal. Other equipments required are: an uncooled parametric preamplifier of sufficiently low temperature to yield an overall system noise temperature of 165° Kelvin, an X-band receiver front end (LO, Mixer, IF) with an approximate 200 MHz 3 dB bandwidth, a 240 Mbps quadraphase (QPSK) demodulator, bit synchronizer and bit detector and data processing and recording equipments as required.

The Low Cost Ground Stations (LCGS) are complete, independent, receive only, ground terminals which will be used by independent observers to receive the lower resolution 20 Mbps BPSK downlink signal from the EOS spacecraft. The LCGS ground terminal parameters (G/T) are chosen to obtain the required 10^{-5} bit error rate. These ground terminals should be built to cost in the range of $75-500K. As currently envisioned, the LCGS will consist of the following: a 6-ft. X-band parabolic dish antenna (this size antenna is required with the baseline S/C ERP to stay within the CCIR recommendations for power flux density), an auto, programmed or manual tracking system depending upon cost, an uncooled parametric amplifier to yield an overall system noise temperature of 165°K, a receiver front end with a 3 dB bandwidth of approximately 30 MHz, a 20 Mbps biphase demodulator, bit synchronization

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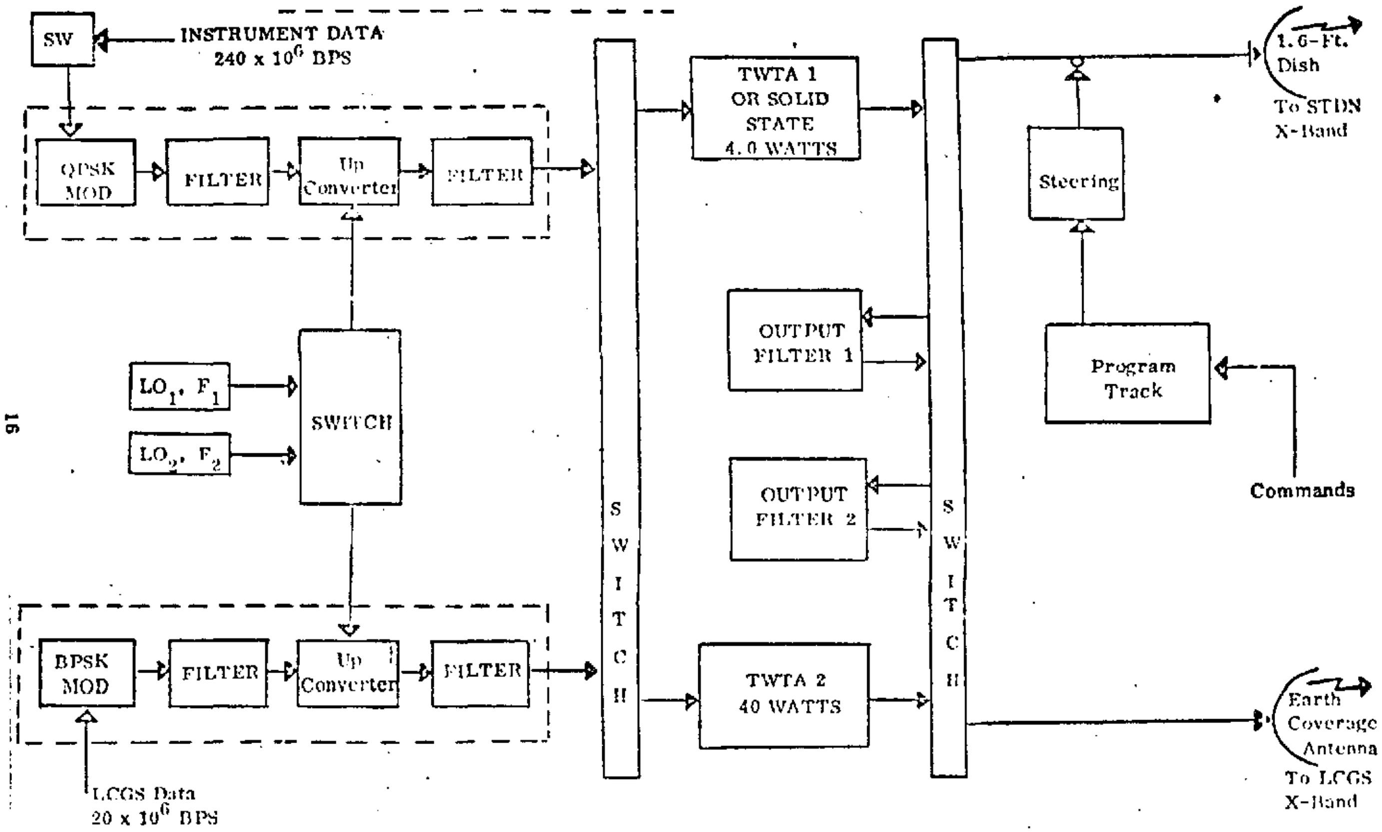


Figure 3-1 . S/C Wideband Communications Subsystem with Earth Coverage Antenna for LCGS Link and bit detector circuitry and recording capability. Some LCGSs may incorporate data processing and handling equipment sufficient to produce a finished data product. However, most stations will merely record data for processing elsewhere.

3.1.3 Cost/Performance Data

The costs associated with implementing the foreign user Regional Ground Terminal for direct transmission will be for a complete X-band ground terminal including data recording and processing. The cost should be less than that for a STDN site due primarily to the smaller antenna size required (18 ft. instead of 30-40 ft.). The ground terminal design is dictated to a large extent by the spacecraft communications subsystem ERP, the data rate and the required bit error rate. The use of a cooled parametric amplifier instead of the proposed uncooled one would reduce the overall system noise temperature and would allow a corresponding reduction in the size of the ground terminal antenna. It is not felt that this would be justified for this design. Very little cost/performance trade-offs are possible for the down converter and IF amplifier designs. The QPSK demodulator also leaves little room for cost trades.

The cost of one or two wideband video tape recorders and data processing equipment must be considered for the Regional ground terminal. The data processing costs will depend upon the degree of processing required for the finished product by the foreign user.

The low cost ground stations will be designed to be as inexpensive as possible (approximately $100K) total cost. The LCGS design is constrained also by the available spacecraft ERP and data rate. The major cost trade areas are the antenna size and type of steering provided and type of preamplifier employed. A considerable savings can be realized if the antenna is programmed tracked instead of auto track and even greater savings if manual tracking is employed. The preamplifier described for the LCGS is an uncooled parametric amplifier with a noise temperature of 165^{o} Kelvin. A substantial reduction in cost would be possible if an FET preamplifier with a noise temperature of 6 dB (870^{o}) was utilized.

Additional cost will be required to provide a wideband video tape recorder capability.

The risks involved in providing the direct transmission option appear to be negligible.

3.2 WIDEBAND VIDEO TAPE RECORDER (WBVTR) SYSTEM

This option includes the addition of a wideband video tape recorder to the spacecraft for recording of data acquired over foreign user areas to be dumped later over a CONUS STDN site (Alaska site provides best coverage). Tapes or finished data products are then shipped to the individual foreign user areas. Since the Alaska STDN site is one of the three sites specified for modification to X-band for EOS use, this station will be capable of receiving and recording the wideband 240 Mbps high resolution data. The tape recorder can also be utilized for the first option considered, Direct Transmission System, to accommodate excess data that cannot be dumped to a foreign user ground station during an individual orbital pass within view of the station.

3.2.1 Spacecraft System Description

The spacecraft system for the WBVTR option will consist primarily of the addition of the recorder and the interfaces required between it and the sensors (HRPI and TM) and the QPSK modulator of the high data rate X-band communications subsystem. Record and operate powers must be considered in the overall spacecraft power profile and spacecraft power subsystem design. These powers are 205 watts during the record mode and 270 watts during the playback mode. The average power per orbit is estimated at 56 watts. The read-in and read-out rate of the recorder is 200 Mbps and the time required to load or unload is 13 minutes resulting in total data storage capacity of 1.56×10^{11} bits. The weight of the recorder and power supply is 225 pounds and the volume is 5.86 cu. ft. The tape length is 6500 ft. with a tape speed not to exceed 100 inches per second. It will also be necessary to provide the interfaces in the EOS S/C to the data communications subsystem and to provide the required primary power.

3.2.2 Ground Terminal Description

As discussed previously, the Alaska STDN site will be converted to X-band for EOS mission use. This will involve providing a new S-band/X-band feed to the 40 ft. parabolic antenna and perhaps a completely new X-band receiver and preamplifier. The received data will undergo either no processing, with shipment of tapes to the foreign user, or will be transmitted via DOMSAT to GSFC for processing prior to shipment of finished products to foreign users.

3.2.3 Cost/Performance Data

The wideband video tape recorder is a new development item in that it is a modification of the ERTS recorder design. It will have a much higher capability than the ERTS recorder, however, it is not anticipated that the cost will be significantly increased over the previous cost. This has been attributed to the learning process that has already transpired. It is estimated that the EOS recorder including integration into the EOS S/C will cost $1.0M.

The major costs involved with the WBVTR option include the recording of the wideband data at the Alaska STDN site and the transmission of the data via DOMSAT or by mail to GSFC, and the costs involved in the processing of the data at GSFC. If the DOMSAT approach is used, it would require the establishment of a DOMSAT terminal at ULA or that the data be relayed to the nearest DOMSAT terminal. Shipment of the tapes by mail to GSFC for processing is obviously the least costly. The use of the DOMSAT would require leasing a number of channels which would be comparatively expensive, however, the foreign user would receive the data in a much more timely fashion.

The individual foreign users must make a decision on cost versus timeliness of data product reception.

The risks of providing the WBVTR as a mission option appear to be small since the basic recorder design is established. However, a considerable weight penalty is involved in providing the WBVTR option (225 lbs.) and if more than one recorder is required the weight could become excessive.

3.3 TRACKING DATA RELAY SATELLITE SYSTEM (TDRSS)

The proposed NASA TDRSS could be used for relay of high data rate information (300 Mbps) between an earth orbiting satellite (altitudes $\leq$ 5000 km) and a central ground station in CONUS (probably White Sands, New Mexico). For altitudes above 1200 km virtually complete coverage is obtained while at the orbit altitude considered for EOS (678 km) a very small zone of exclusion exists. The TDRSS system operates at both S-band and Ku-band with the high data rate single access user spacecraft to Tracking Data Relay Satellite (TDRS) link being at Ku-band. Foreign user data from the EOS spacecraft sensors will be transmitted to the TDRS as the data is being acquired over a user area. The TDRS acts strictly as a bent pipe repeater to relay the data to the CONUS ground station. At the ground terminal, either the data will be recorded on tape without processing and shipped to the foreign users or processing will be performed after the data is routed to GSFC or Sioux Falls via DOMSAT.

3.3.1 Spacecraft System - EOS/TDRSS

The EOS spacecraft communications subsystem will consist of the X-band equipment described in Paragraph 3.1.1 and an additional K_u-band communications subsystem added to enable communication to earth through the Tracking Data Relay Satellite for international data. The K_u-band subsystem required to support a data rate of 240 Mbps at a bit error rate of 10^{-5} is the following: a K_u-band QPSK modulated transmitter with a power output of 16 watts and a steerable 7 ft. diameter K_u-band parabolic dish antenna. Interfaces and switching will be provided to transfer the high rate instrument data between the X-band and the K_u-band subsystems. The X-band communications subsystem is used as described previously for transmission of CONUS acquired data to STDN sites.

The K_u-Band S/C subsystem configuration is given below. Primary EOS spacecraft power required to operate the subsystem is approximately 100 watts.

Alternate K_u-Band S/C Subsystem for TDRSS Operation

Subsystem/Element	Quantity	Size	Weight (Lbs.)	Power (Watts)
K_u-Band Communications Subsystem	1		25.5 Total	100 (Primary)
Includes:				
16 Watt K_u-Band Output Device (TWTA)	1	9" x 10" x 2"	4.0	80.0
QPSK Modulator	1	2" x 3" x 5"	1.0	1.0
Convolutional Encoder	1	1" x 2" x 3"	0.5	1.0
7.0 Ft. Steerable K_u-Band Antenna	1	7 Ft. Diam.	12.0	15.0
Local Oscillator	1	1" x 2" x 2"	1.0	2.0
Up-Converter	1	2" x 2" x 3"	2.0	1.5
TWTA Power Supply	1	3" x 3" x 7"	5.0	

3.3.2 Ground Terminal Description - TDRSS

The TDRSS ground terminal will be located in CONUS and will consist of three K_u-band antennas (two operational and one backup) and operations and support buildings. For EOS international data acquisition, the primary function of the TDRSS ground terminal will be to receive the foreign user data relayed via the TDRS, perform recording and ship the data to the foreign users. The data will also be available as required by interested U.S. agencies. The TDRSS ground terminal will also be used for monitor and control of individual TDRSs.

Since very limited recording capability is planned for the TDRSS ground station, this capability, if required for international data acquisition, must be added to the ground terminal. Present NASA plans are to transmit wideband data from the TDRSS ground terminal via a DOMSAT to GSFC to be processed and recorded there with lower rate data transmitted via microwave relay to Houston. Finished data products could be shipped from GSFC to the foreign user.

3.3.3 Cost/Performance Data

The cost of supplying the additional S/C communications subsystem at K_u-band to enable relay of data through the proposed NASA TDRSS must be considered. It has been estimated that the cost of the spacecraft subsystem will approach $1M. A small recurring operational cost will be required for commanding on-board software for antenna pointing, data transfer, transmitter operation, etc.

One of the most difficult problems associated with providing an EOS spacecraft to TDRS link is the acquisition of the two very narrow beam antennas. The 7 ft. diameter K_u-Band parabolic dish antenna on the EOS spacecraft will have a HPBW of approximately 0.7° and the TDRS 12.5 ft. antenna has a beamwidth of approximately 0.4°. To achieve acquisition, a wider beam antenna must be used on the EOS spacecraft coupled with a spatial search pattern. The necessary electronic circuitry and mechanical dive mechanism must be added as well as circuitry to start and stop search and to switch to this narrow beam antenna after acquisition has been accomplished. The narrow antenna beamwidth also places more rigid requirements on the EOS spacecraft attitude control requirements.

The major risk items to be considered for the TDRSS option are the problems associated with acquisition of the TDRS as discussed above and the availability of a space qualified K_u-Band TWTA in time for the EOS mission. Presently, a 16-watt tube is available and it is believed that with the appropriate funding it could be qualified. The additional spacecraft subsystem weight for the TDRSS option (approximately 26 lbs.) is not considered excessive.

Since the TDRSS is planned by NASA to be available during the EOS mission time-frame, the ground station implementation cost will not be borne by the EOS program. However, very limited recording capability is planned and the costs of increasing the capability will be an EOS program cost. The costs of shipping tapes directly from the TDRSS ground terminal to the foreign user or to GSFC for processing and finished product shipment to the foreign user must be considered. Also, there is the option of using a DOMSAT for transmission of data between the TDRSS and GSFC with the DOMSAT leasing and terminal costs to be considered.

3.4 HYBRID SYSTEMS

The hybrid system most worthy of consideration for EOS international data acquisition is a configuration that would employ both a spacecraft wideband video tape recorder and direct transmission to foreign user ground stations. For this mission option, data would be acquired over the foreign user areas and either transmitted directly to a regional or local user ground station or recorded and dumped at the Alaska STDN site or during a later orbit at a regional or LCGS site. The use of the WBVTR would allow many areas not normally mutually visible between the EOS spacecraft and a ground station to be mapped on a larger number of orbits.

3.4.1 Cost/Performance Data

The major cost considerations for the Hybrid System are the video tape recorder cost (approximately $1M each) and the transmission of data between the Alaska STDN site and GSFC and shipment of finished products to the user as discussed previously. The major increase in performance available with this option is the capability to map foreign user areas not mutually visible from the EOS spacecraft and a foreign user station, store the data and dump it either at a foreign user regional station or the Alaska STDN site. The capability will still exist for mapping and direct transmission to some stations on many orbits.

4.0 SYSTEM COST AND PERFORMANCE SUMMARY

The preceding paragraphs described the basic configuration of each of the alternative IDA systems and the estimated costs of the configuration elements. The discussions in this paragraph will combine these system element costs with estimated data processing and handling (mailing) costs needed to provide quality pictures to the foreign users. In order to estimate the cost impact to EOS of each of the alternative IDA options, a baseline EOS system is assumed to consist of:

Spacecraft

1. TM and HRPI instruments and data handling subsystem
2. Wideband communication subsystem
3. K_u-band transmitter subsystem

Ground System

1. Three primary ground terminals (Alaska, Goldstone and NTTF)
2. Data processing necessary for CONUS collected data only

In addition, the following cost breakdowns and assumptions have been made:

1. Ground terminal and spacecraft impact costs are initial investment costs.
2. Costs are based on a 10 year amortization interval
3. Data processing and handling costs are recurring costs. Processing costs to produce final pictures from S/C wideband data have been estimated to be $ 4M/year. These costs could be higher with a distributed processing configuration such as is envisioned with the D. T. option due to the replication of processing equipments at foreign sites. However in order to simplify the comparative costs of the wideband options a $ 4M/year estimate has been used for all three primary alternative IDA systems.

4. TDRSS costs are assumed to be \$500M or \$50M/year over 10 years
5. The sharing of recurring costs between U.S. and foreign users has not been addressed
6. EOS impact costs are confined to spacecraft costs to implement a particular option since data processing and handling costs have not been proportional between participating users or countries.
7. Data handling (and mailing) costs are a small fraction of the processing costs needed to produce TM or HRPI pictures. Typically \$ 200K/year

The costs of each of the three primary IDA options and a hybrid system configuration is given in Table 4.

The direct transmission case includes the costs of the six regional stations discussed in paragraph 2 (the Indian site is not included) and the data processing and handling costs (per year) required to produce and deliver high quality TM or HRPI pictures every day to each of 20 users per regional station location. The data processing is assumed to be done at the regional station location with final pictures mailed to the local foreign users.

The WBVTR option costs include the costs of 2 recorders on the spacecraft and a equivalent data processing and handling cost to distribute the finished picture products to foreign users. Two tape recorders have been assumed to accommodate cases in which two orbit periods pass before data can be dumped at either Goddard or Alaska.

The TDRSS costs are a function of the cost allocation algorithm assumed for the TDRSS. If the costs are based on percent bandwidth occupancy for the IDA mission, then one-half (\$25M) of the projected yearly TDRSS costs can be assumed. That is, the IDA missions (200 Mbps) use all of the single access capability of a single TDRSS satellite and there are two such satellites in the system. Proportioning costs on the basis of time-bandwidth utilization, on the other hand, would reduce

Table 4. System Cost Breakdowns

Option	Earth Terminal	Spacecraft Costs	\$M/Year Data Processing & Handling Costs	Total Cost (cost impact to EOS)**	
1. D.T. with six regional stations	\$6M	-	\$4.2M	\$10.2M	(0)
2. WBVTR (2 TR's)	-	\$2M	\$4.2M	\$ 6.2M	(\$2M)
3. TDRSS	* \$25M (BW pricing) \$2.5M (BT pricing)	\$1M	\$4.2M	\$30.2M \$ 7.7M	(\$1M) (\$1M)
4. Hybrid*** 6 LCGS & WBVTR (1 TR)	\$0.6M	\$1M	\$0.4M	\$ 2.0M	(\$1M)

*TDRSS - Prorated costs based on bandwidth (BW) proportion used by EOS (\$25M) or bandwidth time product (BT), \$2.5M

**EOS cost impact includes only spacecraft equipment costs

***Primarily intended for low data volume missions this figure by a factor of 1/10th (110 to 150 (worst case) minutes per day projected load)) or \$2.5M per year.

The hybrid system option includes six low cost ground stations (LCGS) and a WBVTR configuration primarily intended for use with a low data volume, wheat crop only, type IDA mission. The LCGSs would be located in South America and Europe (2 in South America and 4 in Europe) and provide direct readout of compacted TM or HRPI data over those areas that could not be recorded and dumped at Alaska or Goddard on the next orbit pass. This option enables the use of only one WBVTR aboard the EOS and is capable of 100% coverage of the wheat crop areas of interest. The processing costs for the compacted data have been estimated at one-tenth the costs of the wideband options due to the reduced data rate capability of this option. Wideband data can be mapped for selected wheat areas of interest by relying on the WBVTR for data collection and accepting the 2-5 (worst case) orbit period delay until the EOS is able to dump this data for CONUS processing.

The cost-effectiveness of each of these options is given in Table 5. The measure used is dollars per minute of available data. For both the total land

Table 5. Cost-Performance Comparison

Option	Thousands of Dollars Minutes of Data	
	% Tilled Land Data	Wheat Crop Data
TDRSS	29.4K/min. (BT costing) 115K/min. (BW costing)	115K/min (BT costing)
WBVTR	31K/min. (2 TR) 41.4K/min. (1 TR)	
D.T.	58.4K/min.	
Hybrid	-	28.6K/min.

area and the tilled land area data volume cases, the TDRSS option gives the best performance in terms of this cost-effectiveness measure ($/minute). This assumes that the BT product costing algorithm applies to TDRSS. If the most expensive ($25M; BW costing) costing algorithm for TDRSS is used, then it would be the least desirable solution. The data for this table was obtained by dividing the cost figures of Table 4 by the performance data of Table 2 for each of the options considered.

Note that the hybrid system gives better results than TDRSS on the basis of low volume wheat crop data and hence is an attractive alternative in this case.

Neither the D. T. or the WBVTR options were considered for the wheat crop only or low data volume case since they are not as cost-effective as the hybrid system. A hybrid system consisting of 2 regional stations (one is South America and one in Europe) and a single WBVTR would not give a cost-effectiveness measure comparable to the TDRSS (BT costing) configuration and hence was not considered in the tilled land area analysis.

5.0 CONCLUSIONS AND RECOMMENDATIONS

The primary conclusions of this study are:

1. For high data volumes, such as the total land area and tilled land area missions assumed in this work, the TDRSS configuration is the most cost-effective of the IDA system options. This conclusion is based on a time-bandwidth product proportioning algorithm for the TDRSS costs.

2. The 2 WBVTR option with data dumps both at Goddard and Alaska is the second choice for the large data volume IDA missions.

3. The cost-effectiveness of the TDRSS configuration is hyper-sensitive to the costing algorithm for the system and in fact impacts the measure so drastically that the TDRSS can be either the best or worst choice depending on the cost allocations employed.

4. A hybrid system of LCGS and a single WBVTR yields the best cost-effectiveness measure for a low data volume scenario such as a wheat crop only mapping mission of foreign sites.

5. The hybrid system allows wideband data processing of selected wheat areas to be accomplished in CONUS provided a delay equivalent to 2 to 5 orbit passes (98 minutes/orbit) is operationally acceptable.

The flexibility and effectiveness of the hybrid system configuration and the cost sensitivity of the TDRSS option form the basis for two recommendations in this study area. First, a hybrid system consisting of a combination of the D. T. and WBVTR configurations should be considered as a candidate for both the high and low volume EOS missions. The number, type and location of foreign based ground stations that complement the WBVTR configuration and provide the optimum cost-effectiveness measure for these missions can be readily established. The present study has demonstrated the cost-effectiveness of a LCGS hybrid and inherent flexibility of a combination of D. T. and WBVTR hybrids. Combinations of regional and LCGS can provide the necessary data volumes at reasonable costs and without the attendent high risks of the TDRSS alternative.

Second, the TDRSS cost-performance sensitivity and planned utilization by other space missions make its viability for the EOS IDA mission highly questionable. The technical risks associated with the acquisition of S/C narrow beamwidth antennas and the development of a space qualified Ku band tube for the EOS time frame are important weighting factors in the establishment of realistic cost-benefit rating for this configuration. It is therefore recommended that a hybrid configuration be considered as the prime back-up IDA configuration for the TDRSS option.

SYSTEM TRADE
STUDY NO. 10

10 USER/SCIENCE AND ORBIT TIME OF DAY STUDIES

10.1 Purpose:

To organize the user requirements for the spacecraft and instrument to provide guidelines for design evaluation.

10.2 Conclusion:

- EOS spacecraft design should be flexible with respect to orbit time of day.
  - Cloud cover for the 900-1100 time period averages 5% less than the 1200-1400 period for CONUS midwest agricultural region, Reference Fig. 10-6.
  - Atmospheric modeling has been used to predict maximum and minimum signal levels in each spectral band. NASA specifications for minimum radiance levels appear to be higher than the calculated values; i.e., for some cases viewing will be instrument limited. See discussion in Section 10.4.6.
  - Sun angle versus orbit time of day does not change rapidly for low sun angles at high latitudes; however, at lower latitudes nearer noon orbits give significantly higher average sun angles, Ref. Fig. 10-5
  - Near noon orbits yield best photometric information (maximum brightness). However, water areas will be affected adversely by sun glint within approximately a 10° cone, while recognition of some types of vegetation is facilitated at or near solar opposition.

- Maximum daytime temperature difference for soils occurs at about 1330, Ref. Fig. 10-7.
- Shadowing at low sun angle is beneficial for such applications as topography and landform.

o EOS system data provided at a frequency of at least 2 weeks will satisfy 72% of the users. It is very desirable to provide data every week or 10 days in which case over 90% of the user applications will be satisfied, Ref. Fig 10-2a.

o EOS data of 30 meters resolution will satisfy 77% of the user applications. Capability of providing 10 meter resolution is desirable to meet the requirements of the remaining 23% applications, Ref. Fig. 10-2b.

o The 4 MSS spectral bands will satisfy 72% of the user applications. The additional 3 bands provided by the TM are desirable in order to satisfy the remaining user applications, Ref. Fig. 10-2c.

o Spectral bands specified for the TM are all useful. Relative priority of the 7 bands are MSS Bands 1, 2, 3 and 4 first priority, and the thermal IR Band 7, (10. to 12.6μ) second priority. Signal to noise problems in band 6 (2.08 to 2.35μ) may make this band of marginal value.

o Radiometric corrections increase in complexity with wider scan angles. The variations in sun angle, atmospheric profiles, ground reflectivity, etc., over the field of view will be investigated and discussed in the final report.

- o All spectral bands of one sensor must be registered within one pixel.
- o It is desirable that each quandrant of a scene have a data point specified with its geographic corrdinates.
- o The major products will probably be 70 mm B&W negatives and CCT's once technology is disseminated
- o Industrial users now account for 37% of Sioux Falls output. This percentage will probably exceed 60% when EOS is launched, due to an anticipated large increase in technology transfer resulting in exponential increase in demand for data, Ref. Fig. 10-1.
- o Monitoring of world food production regions is a very visible application of EOS and warrants emphasis, Ref. Fig. 10-3a,3b,3c,3d,3e,3f, 3g,3h,3i

10.3 Discussion:

10.3.1 User Applications/Requirements

A list of approximately 235 recognized and accepted user applications was employed as the basis for the trade study against which we established system requirements and operational parameters useful in measuring the effectiveness of the EOS system. These user applications versus EOS system requirements are arranged in a matrix format for the disciplines of Agriculture, Forestry, Land Use, Water Resources and Geology. Dr. Marion F. Baumgardner consultant to Grumman, established the items of applications and the data requirements of these applications. Considerable effort was expended to develop a list of applications which would reflect the experience of Dr. Baumgardner in the meaningful application of spacecraft data to terrestrial problems

TITLE USER/SCIENCE AND ORBIT TIME OF DAY STUDIES
APPENDIX E SECTION 10

TRADE STUDY REPORT NO.

WBS NUMBER

With reference to the matrices, Tables 10-1 thru 10-5, in the requirements items are briefly discussed below:

Col. A. Sun Angle - In general a high sun angle is preferred with the exception of some applications where topographic, landform and height information is desired. (A trade-off must be made between cloud build-up, high sun angle, and thermal IR data acquisition. This is discussed in sections 10.4.2, 10.4.3 and 10.4.4.

Col. B. Frequency - Where frequency of data is short, less than 10 days, it is assumed that the time from EOS passage to delivery of data to the user is also short 3 to 5 days. This latter item, throughput requirement, is not included in the matrix. The majority of applications requiring frequent coverage in forests relate to quantity (forest management inventories) and quality (insect infestation or disease breakout). For monitoring agricultural crops many applications require data at one week to 10 day intervals. In as much as agriculture areas are in both north and south latitudes this requirement remains throughout the year and is not seasonal. For water resources information during spring runoff data every 1 to 2 weeks would be very useful.

Table 10-1a. Potential Agricultural Applications of EOS Information Systems   By: Dr. M.F. Baumgardner

APPLICATIONS	A		B	C	D		E SPECTRAL BANDS: THEMATIC MAPPER							F HRPI				G SAR		H		I PRODUCTS					J DISTRIBUTION & USER AGENCIES						REMARKS
	HIGH SUN ANGLE	LOW SUN ANGLE	FREQUENCY WEEKS	RESOLUTION METERS	RAD. CORRECTIONS	GEOM. CORRECTIONS	0.5-0.6 μ	0.6-0.7 μ	0.7-0.8 μ	0.8-1.1 μ	1.55-1.75 μ	2.08-2.35 μ	10.04-12.6 μ	0.5-0.6 μ	0.6-0.7 μ	0.7-0.8 μ	0.8-1.1 μ	"X" Band	"Y" Band	REGISTR. T.M. BANDS	SCENE GEOGR. LOCAT.	70 mm B&W	9x9 B&W	9x9 Color	CCT	MICRO FILM COMP. PRINTOUT	INTERIOR	AGRICULTURE	NOAA	USACE	CRE	EPA	
A. Agricultural Land Resources																																	
1. Agricultural Land use																																	
a. property boundaries	P	A	52	30	N	Y	X	X	X	X	X	X		X	X	X	X					+			+			X					
b. major land units	P	A	104	60	N	Y	X	1	X	1	X	X		X	X	X	X																
c. uses of agricultural structures	P	A	52	10	N	Y	X	X	X	X			X	X	X	X	X					+	-	-	+		X	X	X				
d. cropping systems	P	A	13	60	N	Y	X	1	X	1	1	1	1	X	1	X	1					+	-	-	+			X					Radiometric correction is needed if comparing different dates.
2. Mapping of general cover type & condition																																	
a. vegetation, bare soil, water	P	A	3-6	60	N	Y	X	1	X	1	1	1	1	X	1	X	1			ESSENTIAL FOR ALL APPLICATIONS		+	-	-	+		X	X					Radiometric correction is needed when different dates are compared.
b. cultivated vs. non-cultivated	P	A	26	60	N	N	X	1	X	1	X	X	1	X	1	X	1					+	-	-	+			X					
c. irrigated vs non-irrigated	P	A	13	60	[illegible]	[illegible]	[illegible]	1	X	1	1	1	1	X	1	X	1					+	-	-	+			X					
d. fall plowed vs spring plowed	P	A	10-15	60	N	N	X	1	X	1	X	X	1	X	1	X	1					+			+			X					
e. conventional tillage vs minimum tillage	P	A	52	60	N	N	X	X	X	X	X	X	X	X	X	X	X					+			+			X					
f. harvested vs non-harvested	P	A	1-2	30	N	N	X	X	X	X	X	X	X	X	X	X	X					+			+			X					Applicable only during harvest season.
g. double-cropped vs single cropped	P	A	3-6	30	N	N	X	X	X	X	X	X	X	X	X	X	X					+			+			X					
h. droughty vs non-droughty	P	A	8-12	30	N	N	X	X	X	1	1	1	1	X	X	X	X					+			+			X					
i. wet surface vs dry surface	P	A	2-3	30	N	N	X	X	X	1	1	1	1	X	X	X	X					+			+			X					
3. Land use capability classification & mapping																																	
a. erosion assessment	P	A	2-3	30	N	Y	X	1	X	X	X	X	X	X	1	X	X					+	-	-	+		X	X		X		X	
b. surface drainage	P	A	52	60	N	Y	X	X	X	X	X	X	X	X	X	X	X					+	-	-	+		X	X		X			
c. land forms	A	P	104	30	N	Y	X	1	X	1	X	X	X	X	X	X	X					+	-	-	+		X	X		X			
d. vegetative cover	P	A	4-6	60	N	Y	X	1	1	1	1	1	1	X	1	1	1					+	-	-	+		X	X		X			
B. Crop Resources																																	
1. Crop identification and mapping																																	
a. fields greater than 4 hectares	P	A	12-15	60	N	Y	1	1	1	1	1	1	1	1	1	1	1					+	-	-	+			X					No doubt large data users will use digital analysis. Their product demand will be for CCT's and 70 MM negs.

COL A: P = Preferable, A = acceptable
COL D: N = No, Y = Yes
COL. E, F, G: 1 = Definitely useful
X = May or may not be useful
COL I: + = Major demand
- = Lesser demand

Table 10-1b. Potential Agricultural Applications of EOS Information Systems   By: Dr. M.F. Baumgardner

APPLICATIONS	A: HIGH SUN ANGLE	A: LOW SUN ANGLE	B: FREQUENCY WEEKS	C: RESOLUTION METERS	D: RAD. CORRECTIONS	D: GEOM. CORRECTIONS	E: SPECTRAL BANDS – THEMATIC MAPPER 0.5-0.6 μ	0.6-0.7 μ	0.7-0.8 μ	0.8-1.1 μ	1.55-1.75 μ	2.08-2.35 μ	10.4-12.6 μ	F: MRPI 0.5-0.6 μ	0.6-0.7 μ	0.7-0.8 μ	0.8-1.1 μ	G: SAR "X" Band	"L" Band
b. fields greater than hectare	P	A	12-15	60	N	Y	1	1	1	1	1	1	1	1	1	1	1		
c. fields smaller than 1 hectare	P	A	12-15	30	N	Y	1	1	1	1	1	1	1	1	1	1	1		
2. Crop stress detection																			
a. weed infestation	P	A	1-3	30	Y	Y	X	1	X	1	X	X	1	X	1	X	1		
b. disease damage assessment	P	A	1	30	Y	Y	X	1	X	1	1	1	1	X	1	X	1		
c. drought, moisture stress	P	A	1	30	Y	Y	X	1	1	1	1	1	1	X	1	1	1		
d. excess moisture	P	A	1	30	Y	Y	X	X	1	1	1	1	1	X	X	1	1		
e. salinity	P	A	1-3	30	Y	Y	X	X	X	X	X	X	X	X	X	X	X		
f. nutrient deficiencies	P	A	1	30	Y	Y	X	X	1	1	1	1	X	X	X	1	1		
3. Natural and induced crop destruction																			
a. wind damage, lodging	P	A	1-2	30	Y	Y	X	1	1	1	1	1	1	X	1	1	1		
b. hail damage	P	A	1	30	Y	Y	X	1	1	1	1	1	X	X	1	1	1		
c. flood damage	P	A	1-2	30	Y	Y	X	X	1	1	1	1	X	X	X	1	1		
d. misuse of herbicides	P	A	1-2	30	Y	Y	X	1	1	1	X	X	X	X	1	1	1		
e. fire, burning	P	A	1-3	30	Y	Y	X	X	X	X	X	X	X	X	X	X	X		
4. Crop yield predictions																			
a. crop vigor	P	A	1-2	30	Y	Y	X	1	1	1	1	1	X	X	1	1	1		
b. canopy density	P	A	1-2	30	Y	Y	X	1	1	1	1	1	X	X	1	1	1		
c. rate of growth	P	A	1-2	30	Y	Y	X	1	1	1	1	1	1	X	1	1	1		
d. uniformity of crop	P	A	2-4	30	Y	Y	X	1	1	1	1	1	1	X	1	1	1		
e. crop conditions	P	A	1-2	30	Y	Y	X	1	1	1	1	1	1	X	1	1	1		
5. Areal measurements																			
a. each crop	P	A	8-12	30	Y	Y	X	1	1	1	1	1	1	X	1	1	1		
b. crop stress conditions	P	A	2-4	30	Y	Y	X	1	1	1	1	1	1	X	1	1	1		
c. crops destroyed	P	A	1-3	30	Y	Y	X	1	1	1	1	1	1	X	1	1	1		
d. areas planted, harvested	P	A	1-2	30	Y	Y	X	X	X	X	X	X	X	X	X	X	X		

APPLICATIONS	H: [illegible] T.M. BANDS	SCENE REGIS.	I: PRODUCTS – 70 mm B&W	9x9 B&W	9x9 Color	CCT	MICRO FILM COMP. PRINT	J: DISTRIBUTION & USER AGENCIES – INTERIOR	AGRICULTURE	NOAA	USACE	ONR	EPA	REMARKS
b. fields greater than hectare			+	-	-	+			X					
c. fields smaller than 1 hectare			+	-	-	+			X					
2. Crop stress detection														
a. weed infestation			+			+			X					In most stress detection the user will wish to study or observe the stress change with time. In these cases it will be necessary to have radiometric correction in order to make valid change measurements.
b. disease damage assessment			+			+			X					
c. drought, moisture stress			+			+			X					
d. excess moisture			+			+			X					
e. salinity			+			+			X					
f. nutrient deficiencies			+			+			X					
3. Natural and induced crop destruction														
a. wind damage, lodging	ESSENTIAL FOR ALL APPLICATIONS		+			+			X					One of the prime ultimate users of this kind of information is insurance adjusters and companies. They will wish to compare normal measurements on conditions with damaged conditions. They will also need accurate areal measurements. Therefore, both rad and geo corrections are essential.
b. hail damage			+			+			X					
c. flood damage			+			+		X	X		X		X	
d. misuse of herbicides			+			+			X				X	
e. fire, burning			+			+			X				X	
4. Crop yield predictions														
a. crop vigor			+			+			X					Crop yield prediction models will need to be flexible in order to receive update data from each cloud free satellite pass. Both corrections are necessary.
b. canopy density														
c. rate of growth			+			+			X					
d. uniformity of crop			+			+			X					
e. crop conditions			+			+			X					
5. Areal measurements														
a. each crop			+	-	-	+			X					
b. crop stress conditions			+			+			X					
c. crops destroyed			+			+			X					
d. areas planted, harvested			+			+			X					

COL. A: P = Preferable, A = Acceptable   COL. D: N = No, Y = Yes   COL. E, F, G: 1 = Definitely useful   X = May or may not be useful   Col I: + = Major demand
- = Lesser demand

Table 10-1c. Potential Agricultural Applications of EOS Information Systems By: Dr. M.F. Baumgardner

APPLICATIONS	A: High sun angle	A: Low sun angle	B: Frequency weeks	C: Resolution meters	D: Rad. corrections	D: Geom. corrections	E: Spectral bands, Thematic mapper 0.5-0.6 μ	0.6-0.7 μ	0.7-0.8 μ	0.8-1.1 μ	1.55-1.75 μ	2.08-2.35 μ	10.4-12.6 μ	F: HRPI 0.5-0.6 μ	0.6-0.7 μ	0.7-0.8 μ	0.8-1.1 μ	G: SAR "X" Band	"L" Band	H: Reg. str. T.M. bands	H: Scene geogr. locat.	I: Products 70 mm B&W	9x9 B&W	9x9 Color	CCT	Micro film/comp. printout	J: Distribution to user agencies Interior	Agriculture	NOAA	USACE	CNR	EPA	REMARKS
6. Identifying & characterizing specialty crops																																	
a. vegetables	P	A	6-8	30	Y	Y	X	1	1	1	1	1	1	X	1	1	1					+			+			X					
b. orchards	P	A	6-8	30	Y	Y	X	1	1	1	1	1	1	X	1	1	1					+			+			X					
c. vineyards	P	A	6-8	30	Y	Y	X	1	1	1	1	1	1	X	1	1	1					+			+			X					
C. Livestock Resources																																	
1. Types of Livestock economy																																	
a. confinement feeding	P	A	52	10	N	Y	X	X	X	X	X	X	1	X	X	X	X					+			+			X				X	Confinement feeding operations may be identified only by looking at several dates of data. In this case radiometric correction would be important.
b. intensive pasture	P	A	26	30	N	Y	X	X	X	X	X	X	X	X	X	X	X			ESSENTIAL FOR ALL APPLICATIONS		+			+			X					
c. extensive rangelands	P	A	52	60	N	Y	X	X	X	X	X	X	X	X	X	X	X					+	-	-	+		X	X					
2. Livestock census	P	A	26	10-30	N	N	X	X	X	X	X	X	X	X	X	X	X					+			+		X	X					Livestock census will be done by indirect means not by actual count of animals
D. Rangeland Resources																																	
1. Vegetative cover	P	A	4-6	60	Y	Y	X	1	1	1	1	1	1	X	1	1	1					+	-	-	+		X	X					
2. Assessment of overgrazing	P	A	4-6	60	Y	Y	X	1	1	1	1	1	1	X	1	1	1					+	-	-	+		X	X					
3. Invasion of undesirable species	P	A	26	30	Y	Y	X	X	X	X	X	X	X	X	X	X	X					+	-	-	+		X	X					
4. Carrying capacity assessment	P	A	8-12	60	Y	Y	X	X	X	X	X	X	X	X	X	X	X					+	-	-	+		X	X					
5. Measuring areas destroyed by fire	P	A	26	60	Y	Y	X	1	X	1	X	X	1	X	1	X	1					+	-	-	+		X	X					Coverage required only once as soon as possible after fire.
E. Soil Resources																																	
1. Soil Classification and survey																																	
a. detailed soils maps	P	A	260	30	N	Y	X	1	X	1	X	X	X	X	1	X	1					+			+			X		X			Data should be obtained when there is maximum bare soil
b. soil association maps	P	A	260	60	N	Y	X	1	X	1	Y	X	X	X	1	X	1					+	-	-	+		X	X		X			
2. Available soil moisture	P	A	4-6	60	Y	Y	X	1	X	1	X	X	1	X	1	X	1					+	-	-	+			X	X	X			Useful information during growing season
3. Soil productivity assessment																																	Soil productivity assessment will be determined by a combination of factors, not by a single parameter determined by remote sens.

COL. A: P= Preferable, A= Acceptable COL. D: N= No, Y= Yes COL. E, F, G: 1= Definitely useful X = May or may not be useful
COL. I: + = Major demand - = Lesser demand

Table 10-1d. Potential Agricultural Applications of EOS Information Systems By: Dr. M.F. Baumgardner

	A		B	C	D		E							F				G		H		I					J						
							SPECTRAL BANDS															PRODUCTS					DISTRIBUTION TO USER AGENCIES						
							THEMATIC MAPPER							HRPI				SAR															
APPLICATIONS	HIGH SUN ANGLE	LOW SUN ANGLE	FREQUENCY WEEKS	RESOLUTION METERS	RAD. CORRECTIONS	GEOM. CORRECTIONS	0.5-0.6 u	0.6-0.7 u	0.7-0.8 u	0.8-1.1 u	1.55-1.75 u	2.08-2.35 u	10.4-12.6 u	0.5-0.6 u	0.6-0.7 u	0.7-0.8 u	0.8-1.1 u	"X" Band	"Y" Band	REGISTR. T.M. BANDS	SCENE GEOGR. LOCAT.	70 mm B&W	9x9 B&W	9x9 Color	CCT	MICRO FILM COMP. PRINTOUT	INTERIOR	AGRICULTURE	NOAA	USACE	ONR	EPA	REMARKS
a. soil depth	P	A	260	30	N	Y	X	X	X	X	X	X	X	X	X	X	X					+			+			X					Soil depth measurements with these sensors will be determined indirectly, by inference from other factors. Droughtness will be determined indirectly.
b. droughtiness	P	A	260	30	N	Y	X	1	X	X	X	X	X	X	X	X	X					+			+			X					
c. vigor of vegetation	P	A	13-15	30	Y	Y	X	1	1	1	1	1	X	X	1	1	1					+	-	-	+			X					
4. Erosion	P	A	26	30	Y	Y	X	1	X	1	X	X	X	X	1	X	1					+	-	-	+		X	X				X	
5. Surface drainage patterns	P	A	260	30	N	Y	X	1	X	1	X	X	X	X	1	X	1					+	-	-	+		X	X				X	
6. Internal drainage characteristics	P	A	260	30	N	Y	X	1	1	1	X	X	1	X	1	1	1					+			+			X					

ESSENTIAL FOR ALL APPLICATIONS

COL A: P = Preferable, A = Acceptable
COL D: N = No, Y = Yes

COL. E, F, G: 1 = Definitely useful
X = May or may not be useful

COL I: + = Major demand
− = Lesser demand

Table: 10-2a. Potential Forestry Applications of EOS Information Systems By Dr. M. P. Baumgardner

APPLICATIONS	A: HIGH SUN ANGLE	A: LOW SUN ANGLE	B: FREQUENCY WEEKS	C: RESOLUTION METERS	D: RAD. CORRECTIONS	D: GEOM. CORRECTIONS	E: SPECTRAL BANDS, THEMATIC MAPPER 0.5-0.6 u	E: 0.6-0.7 u	E: 0.7-0.8 u	E: 0.8-1.1 u	E: 1.55-1.75 u	E: 2.08-2.35 u	E: 10.4-12.5 u	F: HRPI 0.5-0.6 u	F: 0.6-0.7 u	F: 0.7-0.8 u	F: 0.8-1.1 u	G: SAR "X" Band	G: "Y" Band	REGISTR. T.M. BANDS	H: SCENE GEOGR. LOCAT.	I: PRODUCTS 70 mm B&W	I: 9x9 B&W	I: 9x9 Color	I: CCT	I: MICRO FILM COMP. PRINTOUT	J: DISTRIBUTION & USER AGENCIES INTERIOR	J: AGRICULTURE	J: NOAA	J: USACE	J: DNR	J: EPA	REMARKS
A. Land Use Inventory																																	
1. Timberline	P	A	52	30	N	Y	X	X	X	X	X	X	X	X	X	X	X				X	+	-	-	+		X	X				X	
2. Timberland-Bushland interface	P	A	52	30	N	Y	X	X	X	X	X	X	X	X	X	X	X				X	+	-	-	+		X	X				X	
3. Timberland-grassland interface	P	A	52	30	N	Y	X	X	X	X	X	X	X	X	X	X	X				X	+	-	-	+		X	X				X	
4. Timberland-rural/urban interface	P	A	52	30	N	Y	X	X	X	X	X	X	X	X	X	X	X				X	+	-	-	+		X	X				X	
5. Timberland-water interface	P	A	52	30	N	Y	X	X	X	X	X	X	X	X	X	X	X				X	+	-	-	+		X	X				X	
B. Forest Land Use																				ESSENTIAL FOR ALL APPLICATIONS													
1. Forest type	P	A	52	30	N	Y	X	X	X	X	1	X	1	X	X	X	X				X	X	-	-	X		X	X					
2. Recreational areas	P	A	52	30	N	Y	X	X	X	X	X	X	X	X	X	X	X				X	X	-	-	X		X	X				X	
3. Wildlife habitat	P	A	2	10	Y	Y	X	X	X	X	X	X	X	X	X	X	X				X	X	-	-	X		X	X					
4. Forage	P	A	2	10	Y	Y	X	X	X	X	X	X	X	X	X	X	X				X	X	-	-	X		X	X					
5. Water resources	P	A	2	10	Y	Y	X	X	X	1	X	X	X	X	X	X	1				X	X	-	-	X		X	X		X		X	
6. Road and rights-of-way	P	A	26	10	N	Y	X	X	X	X	X	X	X	X	X	X	X				X	X	-	-	X		X	X				X	
C. Forest Management Inventory																																	
1. Species	P	A	2-3	10-30	Y	Y	X	X	X	X	1	X	1	X	X	X	X				X	+	-	-	+		X	X					
2. Type & areal extent (Seedling/sapling, pole, cordwood, logs)	P	A	2-3	10-30	Y	Y	X	X	X	X	1	X	1	X	X	X	X				X	+		-	+		X	X					AGE GROUP OF SPECIES
3. Density	P	A	2-3	10-30	Y	Y	X	X	X	X	X	X	X	X	X	X	X				X	+		-	+		X	X					
4. Crown diameter and height	P	A	2-3	10	Y	Y	X	X	X	X	X	X	X	X	X	X	X				X	+		-	+		X	X					
5. Tree Count	P	A	2-3	10	Y	Y	X	X	X	X	X	X	X	X	X	X	X				X	+		-	+		X	X					
6. Yield tables (volumes of specific types)	P	A	2-3	10-30	Y	Y	X	X	X	X	X	X	X	X	X	X	X				X	+		-	+		X	X				X	
7. Forest regeneration inventories	P	A	2-3	10-30	Y	Y	X	X	X	X	X	X	X	X	X	X	X				X	+		-	+		X	X					
8. Cutting progression inventories	P	A	2-3	10-30	Y	Y	X	X	X	X	X	X	X	X	X	X	X				X	+		-	+		X	X				X	

COL A: P = PREFERABLE; A = ACCEPTABLE
COL D: N = NO, Y = Yes

COL. E, F, G: X = Definitely Useful
X = May or May not be Useful

COL I: + = Major demand
- = Lesser demand

Table: 10-2b. Potential Forestry Applications of EOS Information Systems   By: Dr. M. F. Baumgardner

	A		B	C	D		E							F				G		H		I					J						
							SPECTRAL BANDS: THEMATIC MAPPER							HRPI				SAR				PRODUCTS					DISTRIBUTION & USER AGENCIES						
APPLICATIONS	HIGH SUN ANGLE	LOW SUN ANGLE	FREQUENCY WEEKS	RESOLUTION METERS	RAD. CORRECTIONS	GEOM. CORRECTIONS	0.5-0.6 μ	0.6-0.7 μ	0.7-0.8 μ	0.8-1.1 μ	1.55-1.75 μ	2.08-2.35 μ	10.4-12.6 μ	0.5-0.6 μ	0.6-0.7 μ	0.7-0.8 μ	0.8-1.1 μ	"X" Band	"L" Band	REGISTR. T.M. BANDS	SCENE GEOGR. COORD.	70 mm B&W	9x9 B&W	9x9 Color	CCT	MICRO FILM COMP. PRINTOUT	INTERIOR	AGRICULTURE	NOAA	USACE	ONR	EPA	REMARKS
D. Disease and Protection																																	
1. Tree stress and condition	P	A	1-2	10	Y	Y	X	X	X	X	X	X	1	X	X	X	X				X	+			+		X	X					
2. Disease detection	P	A	1-2	10	Y	Y	X	X	X	X	X	X	1	X	X	X	X				X	+			+		X	X					
3. Insect detection	P	A	1-2	10	Y	Y	X	X	X	X	X	X	1	X	X	X	X				X	+			+		X	X					
4. Insect damage assessment	P	A	1-2	10	Y	Y	X	X	X	X	X	X	1	X	X	X	X				X	+			+		X	X					
5. Ground cover	P	A	1-2	10-30	Y	Y	X	X	X	X	X	X	X	X	X	X	X				X	+			+		X	X					GROUND COVER IS A POTENTIAL FIRE HAZARD.
6. Fire detection	P	A	1-2	10-30	Y	Y	X	X	X	X	X	X	1	X	X	X	X				X	+			+		X	X					RESOLUTION DEPENDS ON AREA BURNED.
7. Fire line location and maintenance	P	A	1-2	10	Y	Y	X	X	X	X	X	X	X	X	X	X	X				X	+	-	-	+		X	X					
8. Location, classification of forest fire burns	P	A	1-2	30	Y	Y	X	X	X	X	X	X	1	X	X	X	X				X	+	-	-	+		X	X					X FREQUENCY DEPENDS ON OCCURRENCE OF BURN.
E. Forest Soils																																	
1. Soil classification and mapping	P	A	260	30	N	Y	X	1	X	1	X	X	X	X	1	X	1				X	+	-	-	+		X	X					
2. Soil moisture	P	A	2-3	10	Y	Y	X	X	X	X	X	X	1	X	X	X	X				X	+			+		X	X					
3. Soil productivity	P	A	3-6	30	Y	Y	X	X	X	X	X	X	X	X	X	X	X				X	+			+		X	X					
F. Forest Physiology																																	
1. Forest associations and areal extent	P	A	52	30	N	Y	X	X	X	X	1	X	1	X	X	X	X				X	+	-	-	+		X	X					
2. Evapotranspiration	P	A	1-3	30	Y	Y	X	X	X	X	X	X	1	X	X	X	X				X	+			+		X	X					
3. Biomass estimation	P	A	52	30	N	Y	X	X	X	X	X	X	X	X	X	X	X				X	+			+		X	X					
4. Migration and encroachment	P	A	104	30	N	Y	X	X	X	X	1	X	1	X	X	X	X				X	+			+		X	X					
5. Monitoring spring-fall phenological events	P	A	1-2	30	Y	Y	X	X	X	X	1	X	1	X	X	X	X				X	+			+		X	X					

COL A: P = Preferrable, A = Acceptable
COL D: N = No, Y = Yes

COL E, F, G: 1 = Definitely useful
X = May or may not be useful

COL I: + = Major demand
- = Lesser demand

Table: 10-3a. Potential Land Use Applications of EOS Information Systems By: Dr. M.F. Baumgardner

	A		B	C	D		E							F				G		H		I					J							
							SPECTRAL BANDS															PRODUCTS					DISTRIBUTION & USER AGENCIES							
							THEMATIC MAPPER							HRPI				SAR																
APPLICATIONS	HIGH SUN ANGLE	LOW SUN ANGLE	FREQUENCY WEEKS	RESOLUTION METERS	RAD. CORRECTIONS	GEOM. CORRECTIONS	0.5-0.6 u	0.6-0.7 u	0.7-0.8 u	0.8-1.1 u	1.55-1.75 u	2.08-2.35 u	10.04-12.54 u	0.5-0.6 u	0.6-0.7 u	0.7-0.8 u	0.8-1.1 u	"X" Band	"L" Band	REGISTR. T.M. BANDS	SCENE GEOGR. LOCAT.	70 mm B&W	9x9 B&W	9x9 Color	CCT	MICRO FILM COMP. PRINTOUT	INTERIOR	AGRICULTURE	NOAA	USACE	ONR	EPA	HRPI REQTS.	REMARKS
A. Rural Land Use																																		
1. Agriculture																																		
a. cultivated lands	P	A	26	30	Y	Y	X	1	X	1	X	X	X	X	1	X	1				Y	+	-	-	+		X	X						
b. rangelands	P	A	104	30	N	Y	X	1	X	1	X	X	X	X	1	X	1				Y	+	-	-	+		X	X					D	
c. forests, woodlots	P	A	104	30	N	Y	X	1	X	1	X	X	X	X	X	X	X				Y	+	-	-	+		X	X						Experience to date shows great difficulty in separating forests from mature orchards with dense crown closure.
d. farmsteads	P	A	104	10-30	N	Y	X	X	X	X	X	X	X	X	X	X	X				Y	+			+		X	X					D	
e. non-farm residential	P	A	52	10-30	N	Y	X	X	X	X	X	X	X	X	X	X	X				Y	+			+		X	X					D	Young orchards with low % crown closure and dense grass under-cover cannot be easily separated from meadows and permanent pasture.
f. orchards, vineyards	P	A	26	30	Y	Y	X	X	X	X	X	X	X	X	X	X	X				Y	+			+		X	X						
2. Towns, villages																																		
a. commercial/industrial areas	P	A	52	30	N	Y	X	X	X	X	X	X	X	X	X	X	X			ESSENTIAL FOR ALL APPLICATIONS	Y	+			+		X							
b. public buildings (court houses, schools, churches)	P	A	104	10-30	N	Y	X	X	X	X	X	X	X	X	X	X	X				Y	+			+		X						D	
c. residential areas	P	A	26	10-30	Y	Y	X	X	X	X	X	X	X	X	X	X	X				Y	+			+		X						D	
d. public utility complexes, power stations	P	A	104	10-30	N	Y	X	X	X	X	X	X	X	X	X	X	X				Y	+			+		X					X	D	
3. Other																																		
a. wildlands, wetlands	P	A	26	30	Y	Y	X	X	X	X	X	X	X	X	X	X	X				Y	+	-	-	+		X	X						
b. feedlots	P	A	26	10-30	Y	Y	X	X	X	X	X	X	X	X	X	X	X				Y	+			+		X	X				X	D	
c. parks, golf courses	P	A	26	30	Y	Y	X	X	X	X	X	X	X	X	X	X	X				Y	+			+		X	X						
d. lakes, rivers, streams	P	A	52	30	N	Y	X	X	X	X	X	X	X	X	X	X	X				Y	+	-	-	+		X	X				X		
e. open mines, gravel pits	P	A	52	30	N	Y	X	X	X	X	X	X	X	X	X	X	X				Y	+	-	-	+		X	X				X		
B. Urban Land Use																																		
1. Commercial																																		
a. Inner-city	P	A	52	30	N	Y	X	X	X	X	X	X	X	X	X	X	X				Y	+	-	-	+		X					X		
b. shopping centers	P	A	52	30	N	Y	X	X	X	X	X	X	X	X	X	X	X				Y	+	-	-	+		X							
c. commercial strips along major transportation arteries	P	A	26	30	Y	Y	X	X	X	X	X	X	X	X	X	X	X				Y	+	-	-	+		X							

COL A: P=Preferable, A=Acceptable
COL D: N=No, Y = Yes

COL E, F, G: 1 = Definitely useful
X = May or may not be useful

COL I: + = Major Demand
- = Lesser demand

D = Desirable

Table: 10-3b. Potential Land Use Applications of EOS Information Systems   By: Dr. M.F. Baumgardner

APPLICATIONS	A: HIGH SUN ANGLE	A: LOW SUN ANGLE	B: FREQUENCY WEEKS	C: RESOLUTION METERS	D: RAD. CORRECTIONS	D: GEOM. CORRECTIONS	E: SPECTRAL BANDS – THEMATIC MAPPER 0.5-0.6 u	0.6-0.7 u	0.7-0.8 u	0.8-1.1 u	1.55-1.75 u	2.08-2.35 u	10.4-12.6 u	F: HRPI 0.5-0.6 u	0.6-0.7 u	0.7-0.8 u	0.8-1.1 u	G: SAR "X" Band	"Y" Band	H: REGISTR. T.M. BANDS	SCENE GEOGR. LOCAT.	I: PRODUCTS 70 mm B&W	9x9 B&W	9x9 Color	CCT	MICRO FILM COMP. PRINTOUT	J: DISTRIBUTION & USER AGENCIES INTERIOR	AGRICULTURE	NOAA	USACE	ONR	EPA	HRPI REQTS.	REMARKS
2. Industrial																				ESSENTIAL FOR ALL APPLICATIONS														
a. low density (less than 10% hard surface)	P	A	52	10-30	N	Y	X	X	X	X	X	X	X	X	X	X	X				Y	+			+		X						D	
b. medium density (10-25% hard surface)	P	A	52	10-30	N	Y	X	X	X	X	X	X	X	X	X	X	X				Y	+			+		X						D	
c. high density (greater than 25% hard surface)	P	A	52	10-30	N	Y	X	X	X	X	X	X	X	X	X	X	X				Y	+			+		X						D	
d. warehouse complexes	P	A	52	30	N	Y	X	X	X	X	X	X	X	X	X	X	X				Y	+			+		X							
e. waste disposal sites	P	A	52	30	N	Y	X	X	X	X	X	X	X	X	X	X	X				Y	+			+		X							
3. Institutional																																		
a. churches	P	A	104	10	N	Y	X	X	X	X	X	X	X	X	X	X	X				Y	+			+		X							There is no indication from results of research to date that the items listed under "3 Institutional" can be separated by spectral analysis. It would be very misleading to imply that these separations can be made by either photointerpretation or computer-aided analysis of multispectral scanner data.
b. colleges, universities	P	A	104	30	N	Y	X	X	X	X	X	X	X	X	X	X	X				Y	+			+		X							
c. hospitals, nursing homes, rehabilitation centers	P	A	104	10-30	N	Y	X	X	X	X	X	X	X	X	X	X	X				Y	+			+		X							
d. schools	P	A	104	10-30	N	Y	X	X	X	X	X	X	X	X	X	X	X				Y	+			+		X							
e. government buildings	P	A	104	30	N	Y	X	X	X	X	X	X	X	X	X	X	X				Y	+			+		X							
f. military bases, complexes	P	A	104	30	N	Y	X	X	X	X	X	X	X	X	X	X	X				Y	+			+		X							
g. museums, music halls	P	A	104	30	N	Y	X	X	X	X	X	X	X	X	X	X	X				Y	+			+		X							
4. Open areas																																		
a. cemeteries	P	A	260	30	N	Y	X	X	X	X	X	X	X	X	X	X	X				Y	+			+		X							
b. parks	P	A	52	30	N	Y	X	X	X	1	X	X	X	X	X	X	1				Y	+	-	-	+		X						D	Although many of the urban land uses may not require identification more often than once every two or three years, it may be necessary to analyze multispectral data from two seasons of the year in order to make the desired separations.
c. golf courses	P	A	52	30	N	Y	X	X	X	X	X	X	X	X	X	X	X				Y	+	-	-	+		X						D	
d. atheletic fields	P	A	52	30	N	Y	X	X	X	X	X	X	X	X	X	X	X				Y	+	-	-	+		X						D	
e. lakes	P	A	104	30	N	Y	X	X	X	1	X	X	X	X	X	X	1				Y	+	-	-	+		X						D	
f. woodlots, forests	P	A	104	30	N	Y	X	X	X	X	X	X	X	X	X	X	X				Y	+	-	-	+		X						D	
g. abandoned or unused lots	P	A	52	10-30	N	Y	X	X	X	X	X	X	X	X	X	X	X				Y	+			+		X						D	
h. waste disposal sites	P	A	52	30	N	Y	X	X	X	X	X	X	X	X	X	X	X				Y	+	-	-	+		X					X	D	

COL A: P= Preferable, A= Acceptable
COL D: N= No, Y = Yes

COL. E, F. G: 1 = Definitely useful
X = May or may not be useful

COL I: + = major demand
- = Lesser demand
D = Desirable

Table: 10-3c. Potential Land Use Applications of EOS Information Systems By: Dr. M.F. Baumgardner

APPLICATIONS	A: HIGH SUN ANGLE	A: LOW SUN ANGLE	B: FREQUENCY WEEKS	C: RESOLUTION METERS	D: RAD. CORRECTIONS	D: GEOM. CORRECTIONS	E: SPECTRAL BANDS – THEMATIC MAPPER 0.5-0.6 μ	TM 0.6-0.7 μ	TM 0.7-0.8 μ	TM 0.8-1.1 μ	TM 1.55-1.75 μ	TM 2.08-2.35 μ	TM 10.0-12.6 μ	F: HRPI 0.5-0.6 μ	HRPI 0.6-0.7 μ	HRPI 0.7-0.8 μ	HRPI 0.8-1.1 μ	G: SAR "X" Band	SAR "L" Band	REGISTR. T.M. BANDS	H: SCENE GEOGR. LOCAT.	I: PRODUCTS – 70 mm B&W	9x9 B&W	9x9 Color	CCT	MICRO FILM COMP. PRINTOUT	J: DISTRIBUTION & USER AGENCIES – INTERIOR	AGRICULTURE	NOAA	USACE	ONR	EPA	HRPI REGIS.	REMARKS
5. Residential																																		
a. low density	P	A	52	10-30	N	Y	X	X	X	X	X	X	X	X	X	X	X	X	X		Y	+			+		X						D	
b. medium density	P	A	52	10-30	N	Y	X	X	X	X	X	X	X	X	X	X	X	X	X		Y	+			+		X						D	
c. high density	P	A	52	10-30	N	Y	X	X	X	X	X	X	X	X	X	X	X	X	X		Y	+			+		X						D	
d. apartment building complexes	P	A	52	10	N	Y	X	X	X	X	X	X	X	X	X	X	X	X	X		Y	+			+		X						D	
e. blighted areas	P	A	52	10-30	N	Y	X	X	X	X	X	X	X	X	X	X	X	X	X		Y	+			+		X						D	
C. Transportation																																		
1. Air																																		
a. small airports	P	A	52	10-30	N	Y	X	X	X	X	X	X	X	X	X	X	X	X	X	ESSENTIAL FOR ALL APPLICATIONS	Y	+			+		X					X		
b. commercial air terminals & facilities	P	A	104	30	N	Y	X	X	X	X	X	X	X	X	X	X	X	X	X		Y	+	-	-	+		X					X		
c. military air bases	P	A	104	30	N	Y	X	X	X	X	X	X	X	X	X	X	X	X	X		Y						X							
2. Rail																																		
a. railway lines	P	A	104	10-30	N	Y	X	X	X	X	X	X	X	X	X	X	X	X	X		Y	+			+		X					X	D	
b. railway stations, terminals	P	A	104	10-30	N	Y	X	X	X	X	X	X	X	X	X	X	X	X	X		Y	+			+		X					X	D	
c. railway yards	P	A	104	30	N	Y	X	X	X	X	X	X	X	X	X	X	X	X	X		Y	+			+		X					X		
3. Water																																		
a. inland waterways	P	A	104	10-30	N	Y	X	X	X	X	X	X	X	X	X	X	X	X	X		Y	+	-	-	+		X					X		
b. dock, warf areas	P	A	104	30	N	Y	X	X	X	X	X	X	X	X	X	X	X	X	X		Y	+			+		X					X		
c. harbors	P	A	104	30	N	Y	X	X	X	X	X	X	X	X	X	X	X	X	X		Y	+	-	-	+		X					X		
4. Auto																																		
a. street networks	P	A	52	10	N	Y	X	X	X	X	X	X	X	X	X	X	X	X	X		Y	+			+		X						D	
b. major arteries	P	A	52	30	N	Y	X	X	X	X	X	X	X	X	X	X	X	X	X		Y	+	-	-	+		X					X		
c. interstate highways	P	A	104	30	N	Y	X	X	X	X	X	X	X	X	X	X	X	X	X		Y	+	-	-	+		X					X		

COL A: P = Preferable, A = Acceptable
COL D: N = No, Y = Yes

COL. E, F, G: X = Definitely useful; x - May or may not be useful

COL: I: + = Major demand; - = Lesser demand; D = Desirable

Table: 10-3d. Potential Land Use Applications of EOS Information Systems By: Dr. M.F. Baumgardner

	A		B	C	D		E							F				G		H		I					J						
							SPECTRAL BANDS															PRODUCTS					DISTRIBUTION & USER AGENCIES						
							THEMATIC MAPPER							ERPI				SAR															
APPLICATIONS	HIGH SUN ANGLE	LOW SUN ANGLE	FREQUENCY WEEKS	RESOLUTION METERS	RAD. CORRECTIONS	GEOM. CORRECTIONS	0.5-0.6 u	0.6-0.7 u	0.7-0.8 u	0.8-1.1 u	1.55-1.75 u	2.08-2.35 u	10.4-12.6 u	0.5-0.6 u	0.6-0.7 u	0.7-0.8 u	0.8-1.1 u	"X" Band	"L" Band	REGISTR. T.M. BANDS	SCENE GEOGR. LOCAT.	70 mm B&W	9x9 B&W	9x9 Color	CCT	MICRO FILM COMP. PRINTOUT	INTERIOR	AGRICULTURE	NOAA	USACE	ONR	EPA	REMARKS
D. Socio-Economic Impact																																	
1. Land use changes																																	
a. Identify and monitor types of urban land use changes	P	A	26	10-30	Y	Y	X	X	X	X	X	X	X	X	X	X	X				Y	+	-	-	+		X	X				X	
b. Identify & monitor types of rural land use changes	P	A	26	30	Y	Y	X	X	X	X	X	X	X	X	X	X	X				Y	+	-	-	+		X	X				X	
c. Develop land use prediction model & data base updating	P	A	52	30	N	Y	X	X	X	X	X	X	X	X	X	X	X				Y	+			+		X	X				X	
2. Land use planning																																	
a. assess transportation needs	P	A	52	10-30	N	Y	X	X	X	X	X	X	X	X	X	X	X				Y	+			+		X					X	
b. assess utility needs (communication, energy, water, waste disposal)	P	A	52	10-30	N	Y	X	X	X	X	X	X	X	X	X	X	X			ESSENTIAL FOR ALL APPLICATIONS	Y	+			+		X					X	
c. assess educational requirements	P	A	52	30	N	Y	X	X	X	X	X	X	X	X	X	X	X				Y	+			+		X					X	The population trend problem will have to be determined by relationships with other factors that can be measured by remote sensing. Population cannot be determined directly.
d. estimate population trends	P	A	52	30	N	Y	X	X	X	X	X	X	X	X	X	X	X				Y	+			+		X					X	
e. determine optimum and alternative uses of land	P	A	52	30	N	Y	X	X	X	X	X	X	X	X	X	X	X				Y	+	-	-	+		X					X	
f. determine recreational needs	P	A	52	30	N	Y	X	X	X	X	X	X	X	X	X	X	X				Y	+			+		X	X				X	

COL A: P = Preferable, A = Acceptable
COL D: N = No, Y = Yes

COL E, F, G.: 1 - Definitely useful
X - May or may not be useful

COL I: + = Major demand
- = Lesser demand

D = Desirable

Table: 10-4a. Potential Water Resources Applications of EOS Information Systems By: Dr. M.F. Baumgardner

	APPLICATIONS	A: REQUIREMENTS: HIGH SUN ANGLE	A: LOW SUN ANGLE	B: FREQUENCY WEEKS	C: RESOLUTION METERS	D: RAD. CORRECTIONS	D: GEOM. CORRECTIONS	E: Spectral Bands, Thematic Mapper 0.5-0.6 μ	0.6-0.7 μ	0.7-0.8 μ	0.8-1.1 μ	1.55-1.75 μ	2.08-2.35 μ	10.04-12.6 μ	F: [illegible] 0.5-0.6 μ	0.6-0.7 μ	0.7-0.8 μ	0.8-1.1 μ	G: SAR "X" Band	"L" Band	H: REGISTR. T.M. BANDS	SCENE GEOGR. LOCAT.	I: PRODUCTS 70 mm B&W	9x9 B&W	9x9 Color	CCT	MICRO FILM COMP. PRINTOUT	J: DISTRIBUTION & USER AGENCIES INTERIOR	AGRICULTURE	NOAA	USACE	ONR	EPA	REMARKS
A.	Oceans (Oceanography)																																		
1.	Turbidity (location, amount, type, change)	P	A	13	30-60	Y	Y	X	X	X	X	X	X	X	X	X	X	X	0	0		X	+	-	-	+				X		X		
2.	Chlorophyll distribution	P	A	13	30-60	Y	Y	X	X	X	X	X	X	X	X	X	X	X	0	0		X	+	-	-	+				X		X		
3.	Offshore current monitoring (temperature, extent, dynamics)	P	A	3-6	30-60	Y	Y	X	X	X	X	X	X	I	X	X	X	X	0	0		X	+			+				X		X		
4.	Nearshore currents (location, strength)	P	A	3-6	30	Y	Y	X	X	X	X	X	X	X	X	X	X	X	0	0		X	+	-	-	+				X		X		
5.	Shoreline erosion monitoring	P	A	3-6	30	Y	Y	X	X	X	X	X	X	X	X	X	X	X	X	X		X	+			+		X		X		X		
6.	Fresh water outflow	P	A	13	30	Y	Y	X	X	X	X	X	X	I	X	X	X	X	0	0		X	+			+		X		X		X		
7.	Monitoring spills and leaks	P	A	2-3	30	Y	Y	X	X	X	X	X	X	X	X	X	X	X	X	X		I	+	-	-	+				X		X	X	
8.	Sea ice mapping and monitoring	P	A	2-3	30	Y	Y	X	X	X	X	X	X	X	X	X	X	X	I	I		I	+	-	-	+				X		X		
9.	Iceburgs (location, migration patterns, rate of melting)	P	A	4-6	30-60			X	X	X	X	X	X	X	X	X	X	X	I	I		I	+	-	-	+				X		X		

COL. A: P=PREFERABLE, A=ACCEPTABLE
COL. D: N=NO, Y=YES

COL. EFG:
I=DEFINITELY USEFUL
X=MAY OR MAY NOT BE USEFUL
O=OF LITTLE OR NO USE

COL I:
+ = MAJOR DEMAND
- = LESSER DEMAND

Table 10-4b. Potential Water Resources Applications of EOS Information Systems   By: Dr. M.F. Baumgardner

APPLICATIONS	A		B	C	D		E							F				G		H		I					J						REMARKS
							SPECTRAL BANDS															PRODUCTS					DISTRIBUTION & USER AGENCIES						
							THEMATIC MAPPER							MSS				SAR															
REQUIREMENTS	HIGH SUN ANGLE	LOW SUN ANGLE	FREQUENCY WEEKS	RESOLUTION METERS	RAD. CORRECTIONS	GEOM. CORRECTIONS	0.5-0.6 μ	0.6-0.7 μ	0.7-0.8 μ	0.8-1.1 μ	1.55-1.75 μ	2.08-2.35 μ	10.04-12 μ	0.5-0.6 μ	0.6-0.7 μ	0.7-0.8 μ	0.8-1.1 μ	"X" BAND	"Y" BAND	REGISTR. T.M. BANDS	SCENE GEOGR. LOCAT.	70 mm B&W	9x9 B&W	9x9 Color	CCT	MICRO FILM COMP. PRINTOUT	INTERIOR	AGRICULTURE	NOAA	USACE	ONR	EPA	
B. Inland Surface Water Resources																																	
1. Rivers ans streams																																	
a. water quality (turbidity, chemical and thermal pollution)	P	A	2-3	30	Y	Y	1	1	X	X	X	X	1	1	1	X	X	0	0	X	X	+			+		X			X		X	
b. direction of water flow	P	A	52	30	N	Y	X	X	X	1	X	X	X	X	X	X	1	0	0	0	0	+			+		X			X			
c. river course migration	P	A	26	30	N	Y	X	X	X	1	X	X	X	X	X	X	1	0	0	X	0	+			+		X			X			
d. river channel storage and changes	P	A	2-3	30	N	Y	X	X	X	1	X	X	X	X	X	X	1	0	0	X	0	+			+		X			X			
e. river classification	P	A	260	30	N	Y	X	X	X	X	X	X	X	X	X	X	X	0	0	0	0	+											
f. ice jamming	P	A	2-3	30	N	Y	1	X	X	1	X	X	X	1	X	X	1	1	1	X	X	+			+		X			X			
F. Lakes and reservoirs																																	
a. surface area	P	A	2-3	30	N	Y	X	X	X	1	X	X	X	X	X	X	1	0	0	0	0	+			+		X			X			
b. storage capacity and changes	P	A	2-3	30	N	Y	X	X	X	1	X	X	X	X	X	X	1	0	0	0	0	+			+		X			X			
c. water quality (turbidity, chlorophyll and algae concentration and algae concentration and distribution, eutrophication rates)	P	A	2-3	30	Y	Y	1	1	X	X	X	X	X	1	1	X	X	0	0	X	X	+			+		X			X		X	
d. sedimentation rates	P	A	13	30	Y	Y	X	X	X	X	X	X	X	X	X	X	X	X	X	0	0	+			+		X			X		X	
e. temperature distribution, location of thermal anomalies	P	A	13	30	Y	Y	0		0	0	0	0	1	0	0	0	0	0	0	0	X	+			+		X			X			
f. circulation patterns	P	A	26	30	N	Y	X	X	X	X	X	X	X	X	X	X	X	0	0	X	X	+			+		X			X			
g. evaporation	P	A	2-3	30	Y	Y	X	X	X	X	X	X	X	X	X	X	X	0	0	0	0	+			+		X			X			
h. lake classification, morphology	P	A	104	30 60	N	Y	X	X	X	X	X	X	X	X	X	X	X	0	0	0	0	+			+		X			X			
i. lake ice surveillance	P	A	2-3	30	N	Y	1	X	X	1	X	X	X	1	X	X	1	1	1	X	1	+											

COL. A: P=PREFERABLE, A=ACCEPTABLE
COL. D: N=NO Y=YES

COL. EFG:
1=DEFINITELY USEFUL
X=MAY OR MAY NOT BE USEFUL
0=OF LITTLE OR NO USE

COL I:
+ = MAJOR DEMAND
- = LESSER DEMAND

Table 10-4c. Potential Water Resources Applications of EOS Information Systems By: Dr. M.F. Baumgardner

APPLICATIONS	REQUIREMENTS	HIGH SUN ANGLE	LOW SUN ANGLE	FREQUENCY WEEKS	RESOLUTION METERS		RAD. CORRECTIONS	GEOM. CORRECTIONS	SPECTRAL BANDS: THEMATIC MAPPER 0.5-0.6 μ	0.6-0.7 μ	0.7-0.8 μ	0.8-1.1 μ	1.55-1.75 μ	2.08-2.35 μ	10.4-12.6 μ	HRPI 0.5-0.6 μ	0.6-0.7 μ	0.7-0.8 μ	0.8-1.1 μ	SAR "X" Band	"L" Band	REGISTR. T.M. BANDS	SCENE COORD. LOCAT.	PRODUCTS: 70 mm B&W	9x9 B&W	9x9 Color	CCT	MICRO FILM COMP. PRINTOUT	DISTRIBUTION & USER AGENCIES: INTERIOR	AGRICULTURE	NOAA	USACE	OEP	EPA	REMARKS
C. Groundwater Resources																																			
1. Soil moisture		P	A	1-2	10	30	Y	Y	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	+			+		X	X	X				
2. Relative depth to aquifer		P	A	26	30		N	Y	X	X	X	X	X	X	X	X	X	X	X	X	0	0	0	+			+		X	X	X				
3. Groundwater (deep well) irrigation		P	A	52	30		N	Y	X	X	X	X	X	X	X	X	X	X	0	0	0	0	0	+			+		X	X	X				
4. Water plant propagation and control		P	A	26	30		N	Y	X	X	X	X	X	X	X	X	X	X	X	0	0	X	X	+			+		X	X					
5. Discharge into streams (base flow)		P	A	6-8	10		Y	Y	X	X	X	X	X	X	X	X	X	X	X	0	0	0	0	+			+		X	X					
D. Snow Resources																																			
1. Snowline changes		P	A	1-2	30		Y	Y	1	1	X	X	1	1	X	1	1	X	X	X	X	X	X	+	-		+		X			X			
2. Areal extent		P	A	1-2	30		Y	Y	1	1	X	X	1	1	X	1	1	X	X	X	X	X	X	+	-		+		X			X			
3. Thickness		P	A	1-2	30		Y	Y	1	1	X	X	1	1	X	1	1	X	X	X	X	X	X	+			+		X						
4. Moisture equivalent		P	A	2-3	30		Y	Y	1	1	X	X	1	1	X	1	1	X	X	X	X	X	X	+			+		X						
5. Age		P	A	2-3	30		Y	Y	1	1	X	X	1	1	X	1	1	X	X	X	X	0	0	+			+		X						
6. Nature		P	A	6-12	30		Y	Y	1	1	X	X	1	1	X	1	1	X	X	X	X	0	0	+			+		X						
7. Melting rate		P	A	1-2	30		Y	Y	1	1	X	X	1	1	X	1	1	X	X	X	X	0	0	+			+		X	X		X			
8. Albedo changes		P	A	1-2	30		Y	Y	1	1	X	X	0	0	X	1	1	X	X	0	0	0	0	+			+		X						
9. Runoff prediction		P	A	1-2	30		Y	Y	1	1	X	X	X	X	X	1	1	X	X	X	X	0	0	+			+		X	X		X			

COL. A: P=PREFERABLE A=ACCEPTABLE
COL. D: N=NO Y=YES

COL. E&G:
1=DEFINITELY USEFUL
X=MAY OR MAY NOT BE USEFUL
0=OF LITTLE OR NO USE

+=MAJOR DEMAND
-= LESSER DEMAND

Table: 10-4d. Potential Water Resources Applications of EOS Information Systems   By: Dr. M.F. Baumgardner

APPLICATIONS	REQUIREMENTS: HIGH SUN ANGLE (A)	LOW SUN ANGLE	FREQUENCY WEEKS (B)	RESOLUTION METERS (C)	RAD. CORRECTIONS (D)	GEOM. CORRECTIONS	SPECTRAL BANDS: THEMATIC MAPPER (E) 0.5-0.6 μ	0.6-0.7 μ	0.7-0.8 μ	0.8-1.1 μ	1.55-1.75 μ	2.08-2.35 μ	10.4-12.? μ	HRPI (F) 0.5-0.6 μ	0.5-0.7 μ	0.7-0.8 μ	0.8-1.1 μ	SAR (G) "X" Band	"L" Band	REGISTR. T.M. BANDS (H)	SCENE GEOGR. LOCAT.	PRODUCTS (I): 70 mm B&W	9x9 B&W	9x9 Color	CCT	MICRO FILM COMP. PRINTOUT	DISTRIBUTION & USER AGENCIES (J): INTERIOR	AGRICULTURE	NOAA	USACE	CIR	EPA	REMARKS
E. Ice Resources																																	
1. Glaciers																																	
a. areal extend	P	A	26	30	N	Y	I	I	X	X	X	X	X	I	I	X	X	X	X		X	+	-		+		X		X				
b. thickness	P	A	26	30	N	Y	I	I	X	X	X	X	X	I	I	X	X	X	X		X	+	-		+		X		X				
c. seasonal changes	P	A	26	30	N	Y	Y	I	X	X	X	X	X	I	I	X	X	X	X		X	+	-		+		X		X				
d. movement rates	P	A	26	30	N	Y	I	I	X	X	X	X	X	I	I	X	X	X	X		X	+	-		+		X		X				
2. Permafrost boundaries	P	A	26	30	N	Y	X	I	X	I	X	X	X	X	I	X	I	X	X		X	+	-		+		X						
F. Watershed Mapping and Monitoring																																	
1. Type and density of drainage patterns	P	A	104	30 60	N	Y	X	I	X	I	X	X	X	X	I	X	I	X	X		X	+	-	-	+		X	X					
2. Changes in drainage patterns	P	A	52	30	N	Y	X	I	X	I	X	X	X	X	I	X	I	O	O		X	+	-	-	+		X	X					
3. Drainage network mapping	P	A	104	30	N	Y	X	I	X	I	X	X	X	X	I	X	I	X	X		X	+	-	-	+		X	X					
4. Artificial drainage features (dams, ditches..)	P	A	104	30	N	Y	X	X	X	X	X	X	X	X	X	X	X	O	O		X	+			+		X	X					
5. Basin runoff prediction and management	P	A	13	30	Y	Y	X	X	X	X	X	X	X	X	X	X	X	O	O		X	+			+		X	X					
6. Surface water inventory	P	A	2-3	30	Y	Y	X	X	X	I	X	X	X	X	X	X	I	O	O								X	X	X	X			
7. Ground slopes	P	A	260	30	N	Y	X	X	X	X	X	X	X	X	X	X	X	X	X		X	+			+		X	X					
8. Drainage basin divides mapping	P	A	260	30	N	Y	X	X	X	X	X	X	X	X	X	X	X	X	X		X	++	-	-	+		X	X					
9. Irrigation systems	P	A	104	30	N	Y	X	I	X	I	X	X	X	X	I	X	I	O	O		X	+			+		X	X					
10. Estimates of annual precipitation	P	A	4-6	30	Y	Y	X	I	X	I	X	X	X	X	I	X	I	O	O		X	+			+		X	X	X	X			
11. Erosion measurements and prediction	P	A	4-6	30	Y	Y	X	X	X	X	X	X	X	X	X	X	X	O	O		X	+			+		X	X				X	
																						+			+								

COL: A: P=PREFERABLE A=ACCEPTABLE
COL: D: N=NO Y=YES

COL. EFG:
I=DEFINITELY USEFUL
X=MAY OR MAY NOT BE USEFUL
O=OF LITTLE OR NO USE

COL. I:
+=MAJOR DEMAND
-=LESSER DEMAND

Table: 10-5. Potential Geological Applications of EOS Information Systems By: Dr. M.F. Baumgardner

APPLICATIONS	A: High sun angle	A: Low sun angle	B: Frequency weeks	C: Resolution meters	D: Rad. corrections	D: Geom. corrections	E: Spectral bands, Thematic Mapper 0.5-0.6 µ	0.6-0.7 µ	0.7-0.8 µ	0.8-1.1 µ	1.55-1.75 µ	2.08-2.35 µ	10.4-12.6 µ	F: RBV 0.5-0.6 µ	0.5-0.7 µ	0.7-0.8 µ	0.8-1.1 µ	G: SAR "X" Band	SAR "L" Band	H: Registr. T.M. Band	Scene coord. locat.	I: Products 70 mm B&W	9x9 B&W	9x9 Color	CCT	Micro film comp. printout	J: Distribution to user agencies: Interior	Agriculture	NOAA	USACE	ONR	EPA	REMARKS
A. Extractive																																	
1. location of coal deposits	P	A	13	30	Y	Y	1	1	1	1	X	X	X	1	1	1	1					+	-	-	+		X					X	With ERTS data the geologists have found it very useful to be able to study false color images and other color enhancement techniques. If these color composites are produced by computor from CCT's a better resolution can be achieved from with the 1:1,000,000 scale color composites produced by NASA and EROS data center.
2. location of exploitable aquifers	P	A	13	30	Y	Y	1	1	1	1	X	X	X	1	1	1	1					+	-	-	+		X		X			X	
3. location of mineral deposits	B	B	13	30	Y	Y	1	1	1	1	X	X	X	1	1	1	1					+	-	-	+		X					X	
4. location of petroleum deposits	A	P	13	60	Y	Y	1	1	1	1	X	X	X	1	1	1	1					+	-	-	+		X					X	
5. location of stone for quarrying	P	A	26	30	Y	Y	1	1	1	1	X	X	X	1	1	1	1					+	-	-	+		X					X	
6. delineation of sand and gravel deposits	P	A	26	30	Y	Y	1	1	1	1	X	X	X	1	1	1	1					+	-	-	+		X					X	
B. Structural																																	
1. regional tectonic provinces	A	P	260	60	N	Y	1	1	1	1	X	X	X	1	1	1	1	X	X			+	-	-	+		X					X	
2. local structural features	A	P	260	30 60	N	Y	1	1	1	1	X	X	X	1	1	1	1	X	X			+	-	-	+		X					X	
3. land from analysis	A	P	260	30	N	Y	1	1	1	1	X	X	X	1	1	1	1	X	X			+	-	-	+		X					X	
4. mapping of lineaments, fractures	A	P	13	60	Y	Y	1	1	1	1	X	X	X	1	1	1	1	X	X			+	-	-	+		X					X	
C. Thermal																																	
1. geothermal anomalies	P	A	13	30	Y	Y	X	X	X	X	X	X	1	X	X	X	X					+			+		X						
2. volcanic activity	P	A	1 2	60	Y	Y	X	X	X	X	X	X	1	X	X	X	X					+			+		X						
D. Geologic hazards																																	
1. earth movement	P	A	1 2	10 30	Y	Y	1	1	1	1	X	X	X	1	1	1	1	X	X			+	-	-	+		X					X	
2. monitoring ice fields	P	A	13	60	Y	Y	X	X	X	X	X	X	X	X	X	X	X	X	X			+	-	-	+		X						
3. monitoring coastal features	P	A	13	60	Y	Y	1	1	1	1	X	X	1	1	1	1	1	X	X			+	-	-	+		X		X	X		X	
4. volcano eruptions	P	A	1 2	60	Y	Y	X	X	X	X	X	X	1	X	X	X	X					+	-	-	+		X		X	X			
E. Other																																	
1. mapping geologic features	P	A	260	30	N	Y	1	1	1	1	X	X	X	1	1	1	1	X	X			+	-	-	+		X						
2. identification of rock types	P	A	13	10 30	Y	Y	X	X	X	X	X	X	X	X	X	X	X					+	-	-	+		X						
3. geomorphology	A	P	260	30	N	Y	1	1	1	1	X	X	X	1	1	1	1	X	X			+	-	-	+		X						
4. rock alteration	P	A	13	10 30	Y	Y	X	X	X	X	X	X	X	X	X	X	X					+	-	-	+		X						

Registration of bands is essential for all applications. Precessgeographical coordinates

should be marked in data. Registration of bands is essential for all applications.

Col C Resolution - The resolution number entered does not imply that a larger resolution is worthless, but rather that the smaller number 30m or 10 m for example will be useful for the particular application. Forestry application can use 60 meter resolution for identifying cover of one hectare while 30 meter resolution is needed when dealing with a single species in heterogenous mixtures. Ten meter resolution is beneficial in developing volume equations and monitoring disease, stress and insect conditions.

The U.S. agricultural areas include large fields when compared to important agricultural areas in other countries. In designating agricultural resolution requirements major emphasis was given to the U.S. Thirty (30) meter resolution (equivalent to 0.25 acreas) is adequate for most applications, although many do not require such detail.

For water resource applications 60 meters resolution is adequate for the larger bodies of water. For rivers, small lakes, etc. 30 meter resolution will be a benefit. For water quality applications 30 meter resolution would be helpful.

Col D Radiometric and Geometric Corrections - It is assumed that the radiometric corrections will be within 5% and the geometric corrections within 3 pixels.

Many forest applications do not require radiometrically corrected data for analysis and interpretation of a single scene for a single date. However, quantitative determinations of forest species and forest conditions will require radiometric corrections. The thermal bands must be calibrated in order to provide quantified temperature differences.

Agricultural applications requiring comparisons or overlay of EOS scenes acquired on different passes benefit considerably if data is radiometrically corrected. In some instances it is a necessity.

Water resource applications dealing with turbidity, sedimentation plumes, etc. require radiometric calibration unless dealing with a single scene on a single date. Calibration of thermal data is necessary for quantitative temperature differences.

Geometric corrections are needed for HRPI nadir pointed where 10 meter resolution is required. For comparison of data from different EOS passed geometrical corrections are essential.

<u>Cols.E,F - Spectral Bands</u> - As yet the research community has not come up with documentation for an adequate definition of the spectral bands which are most useful for many applications. However, the TM spectral bands are useful for separating certain features of importance to agriculture.

For soils studies bands 0.6-0.7µ and 0.8-1µ have been found particularly useful. For crop species identification, a thermal band, one or two reflective IR bands, and the upper visible region have been found useful. For vegetation under stress near IR, middle IR and thermal IR have been found to be important.

Experience with aircraft data indicate that thermal scanning may be important for studying internal drainage properties of soils and for studying moisture stress in plants. The middle IR bands may also be useful in characterizing plant moisture stress. For snow areal extent measurements and determination of moisture equivalent the middle IR bands of the TM are essential.

For the High Resolution Pointable Imager the four spectral bands used on ERTS-1 seem feasible. The HRPI with its pointing capability will offer the possibility of monitoring particular sites more often than can be done with the TM. While offering specific advantages, this feature introduces many special problems. The distortions introduced by oblique viewing will make geometric corrections and temporal overlay quite difficult. For these and other reasons perhaps it is wise to include in this complex scanner only four simple wide bands.

Column G Synthetic Aperture Radar - No very convincing evidence has yet been presented for the use of SAR for the agricultural applications considered herein. SAR does provide all weather capability in that is has the capability of penetrating cloud cover and viewing the earth's surface. The capability of SAR to identify and characterize earth surface features does not approach the capability of the multispectral scanner to perform such tasks.

The SAR does lend itself to the mapping of gross features and geometric patterns. It has been useful in mapping the locations and shapes of lakes, rivers, and land forms in regions of perpetual cloud cover.

Radar has also been suggested as a tool for determining soil moisture. Its use for this task has been carefully examined. This application is so fraught with uncontrollable variables that it does not appear to be satisfactory.

Col H Registration - Since most applications will require the analysis of more than a single band of spectral data, it is essential that all bands for the Thematic Mapper and all bands for the HRPI be registered.

It would be most helpful if each quadrant of a frame of EOS TM data has a data point which is registered precisely with a specific geographical coordinate or address.

Many forest applications will require 10 meter resolution and registration of the data bands. Utilizing the HRPI in a vertical mode (principal image point = nadir) registration would be simplified. However, if the instrument must be pointed the following information would be important to the user: location of TM nadir point, principal point of HRPI, angular displacement of principal point from nadir and the direction of displacement.

Col I Products - There is strong evidence today that the trend over the next five years will be towards the digital analysis of multispectral data from future satellite information systems. If indeed this is the case there will be numerous centers by the time EOS is launched that will have the capability for digital processing and analysis.

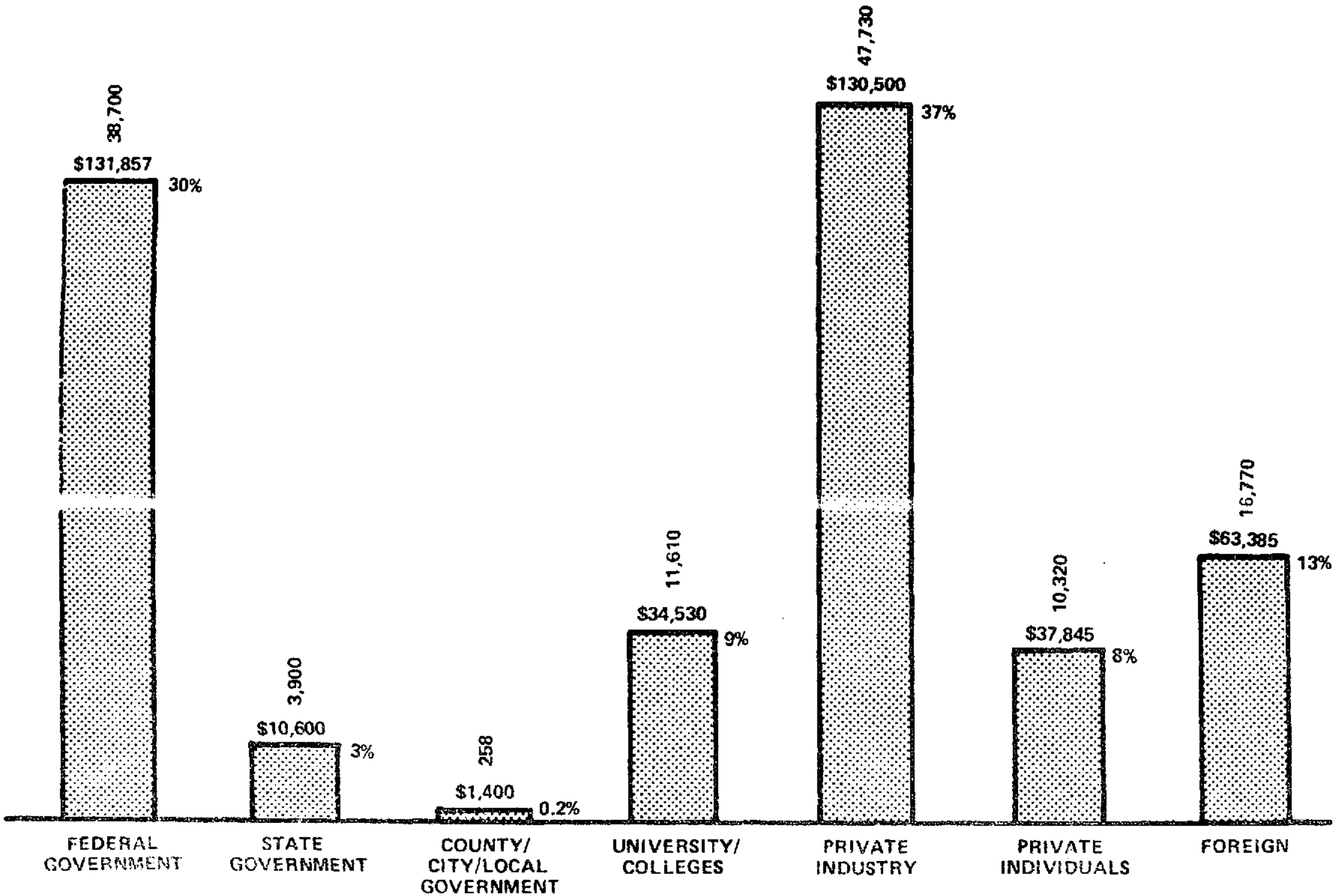
It seems reasonable to anticipate that the main data products will be 70 mm b & w negatives and computer compatible tapes. The user can then produce his own b & w prints and enlargements for quick look analysis or for detailed photointerpretation. The CCTs can be used for more quantitative analytical treatment and production of images at larger scale than can be achieved by photographic production of enlargements from 70 mm negatives. Microfilm of CCT printouts could be supplied to those users who lack computer facilities, but who have a requirement to analyze the scene using the data with minimum spatial, spectral and geometric degradation.

The enormous quantity of data to be generated by EOS of necessity requires digital analysis by users who expect to take full advantage of the EOS system.

A user who wishes to have false color images may produce them by compositioning the appropriate bands of data, photographically or digitally. There will be many users of limited quantities of data who will not have computer facilities. In such cases, NASA, the EROS Data Center, or some other facility with the essential hardware and software (such as LARS) can produce the desired product for the user, or provide the user with a remote terminal.

It is impossible now to predict with any certainty what data products will be in greatest and least demand in 1980. One of the critical gaps in the remote sensing field is the lack of awareness and training among potential users of this new technology.

CUSTOMER PROFILE
(JULY '72—DEC. '73)



TOTAL FRAMES — 129,288
TOTAL VALUE — $410,117.00

FIG: 10-1
COURTESY DEPT. INTERIOR
EROS DATA CENTER

The learning curve is still relatively flat. Once this curve turns up and the knowledge of how to make use of the remote sensing information systems there will probably be a great increase in the demand for satellite images of small and very specific areas. With reference to Fig. 10-1, the industrial users obtained more data from the EROS Program, Sioux Falls than the Federal Government. This appears to be the beginning of a much greater demand from industry. In anticipation of this demand surge, each scene should be deliverable (optically and digitally) as $\frac{1}{4}$ scenes with geometric locating bits for each quadrant.

10.3.2 APPLICATIONS/REQUIREMENTS SUMMARY

The primary system drivers in the area of user data requirements are frequency of data, spatial resolution, and spectral bands. The requirements listed on the matrices (Table 1-5), were summarized for each discipline and then averaged for all disciplines. Bar charts of the results are shown in Fig. 10-2a, 2b, 2c. For the discipline of agriculture of the 62 user applications listed, 18 (29%) require or will materially benefit from weekly data; whereas, 37 applications (60%) require data only at a frequency greater than 3 weeks (or one orbital cycle). A listing of the requirements of the 235 applications averaged without weighting is given in Table 6 below:

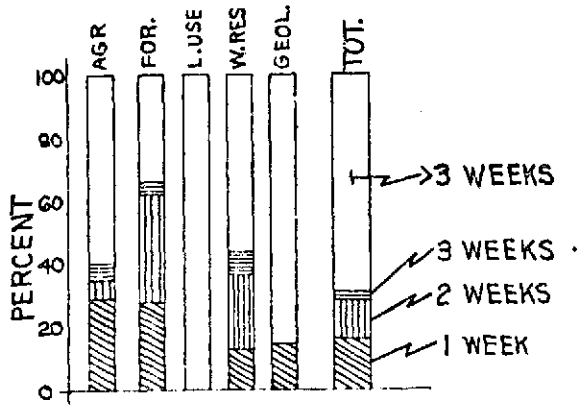


FIGURE 10-2a

USER REVISIT TIME REQUIREMENTS

o LARGEST PERCENTAGE GREATER THAN 3 WEEKS

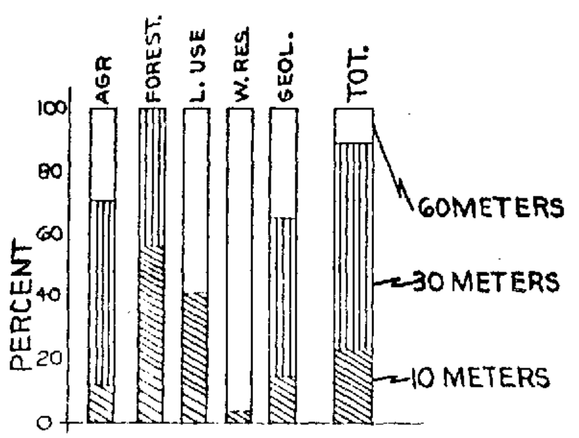


FIGURE 10-2b

USER RESOLUTION REQUIREMENTS

o DEVELOP MULTI-RESOLUTION SYSTEMS TO SATISFY USER REQUIREMENTS

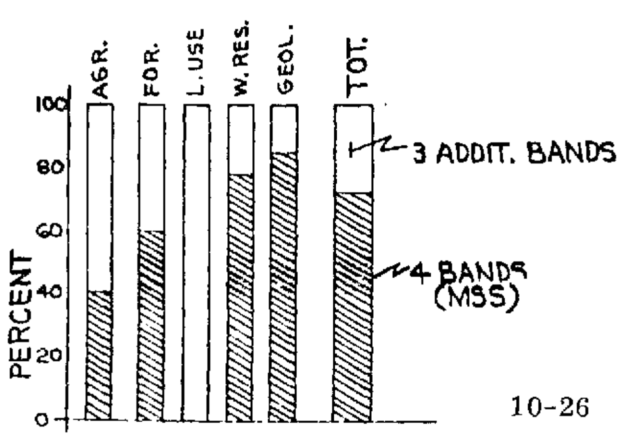


FIGURE 10-2c

USER SPECTRAL REQUIREMENTS

o LARGE PERCENTAGE REQUIRES ADDITIONAL BANDS

TABLE 10-6

DATA CHARACTERISTICS VS APPLICATIONS

(Averaged without Weighting)

Frequency:

Greater than 3 weeks satisfies 69% of applications

3 weeks satisfies 72% of applications

2 weeks satisfies 84% of applications

1 week satisfies 100% of applications

Resolution:

60 meters satisfies 11% of applications

30 meters satisfies 77% of applications

10 meters satisfies 100% of applications

Spectral Bands:

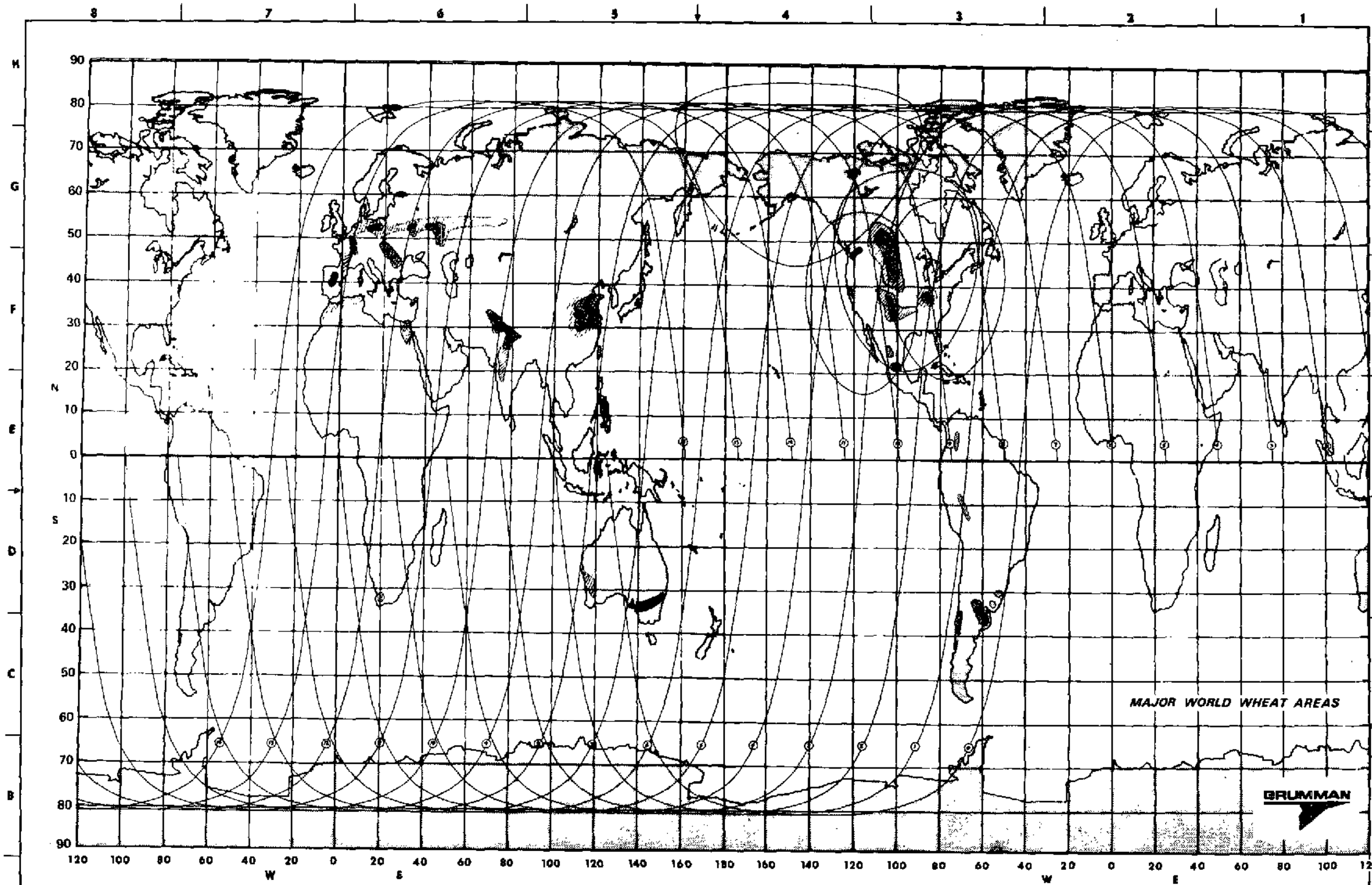
4 MSS Bands satisfy 72% of applications

4 MSS Bands plus 3 additional TM bands satisfy 100% of application.

10.3.3 USER REQUIREMENTS ON EOS TO COVER THE LAND MASS AND MAJOR AGRICULTURAL REGIONS OF THE WORLD

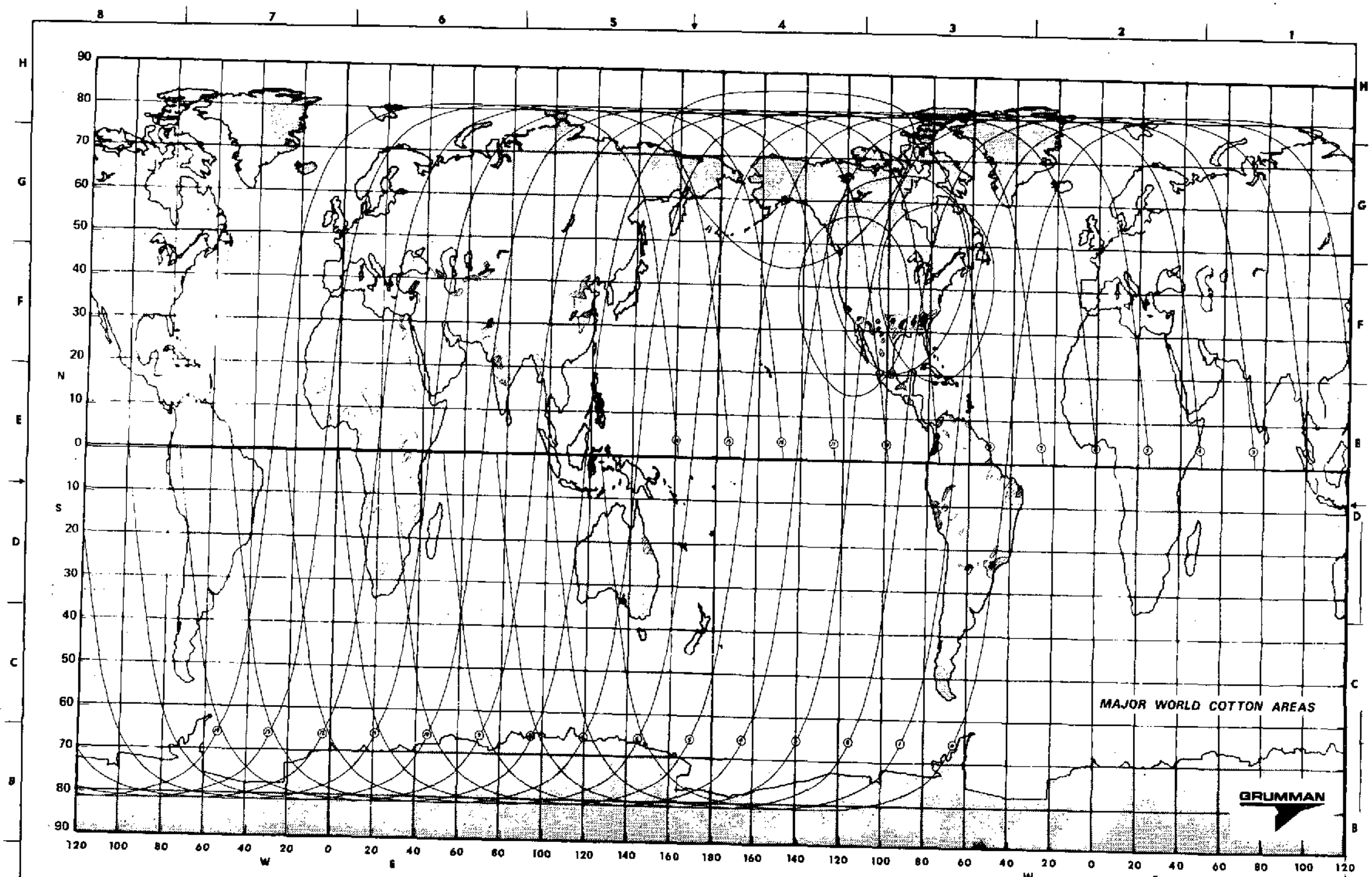
(The impact of the international data acquisition load on the EOS system design is treated in section 9 of this appendix).

Dr. M.F. Baumgardner, (Agronomist, LARS Purdue) delineated the major agricultural regions of the world shown on Figs. 10-3a through 10-3i. These regions are under pressure to expand food production. We examined each of the major food crops to determine the average daily data load on the EOS.



E-57

Fig. 10-3a EOS Coverage of Major World Wheat Areas



E-49

Fig. 10-3b EOS Coverage of Major World Cotton Areas

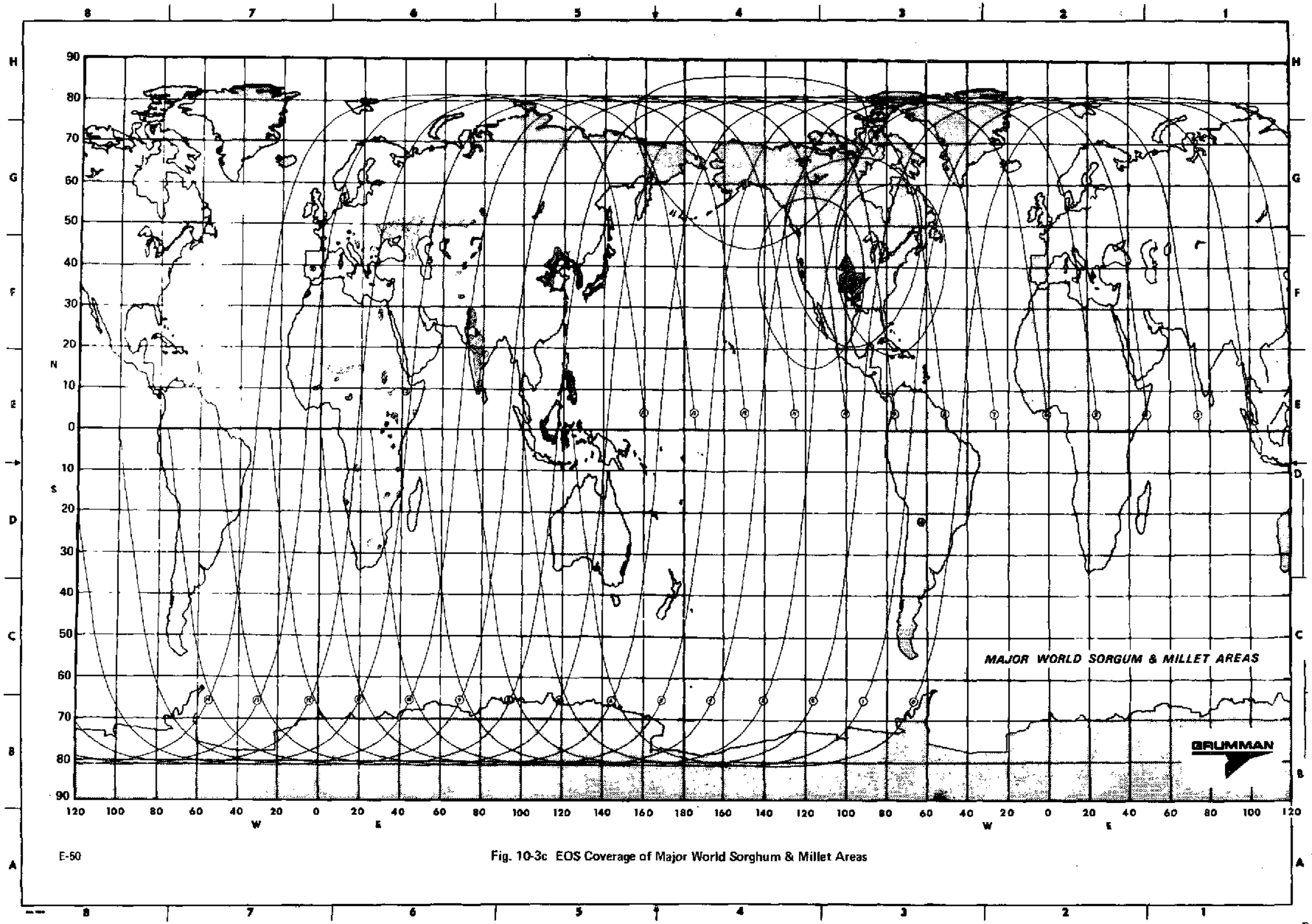


Fig. 10-3c EOS Coverage of Major World Sorghum & Millet Areas

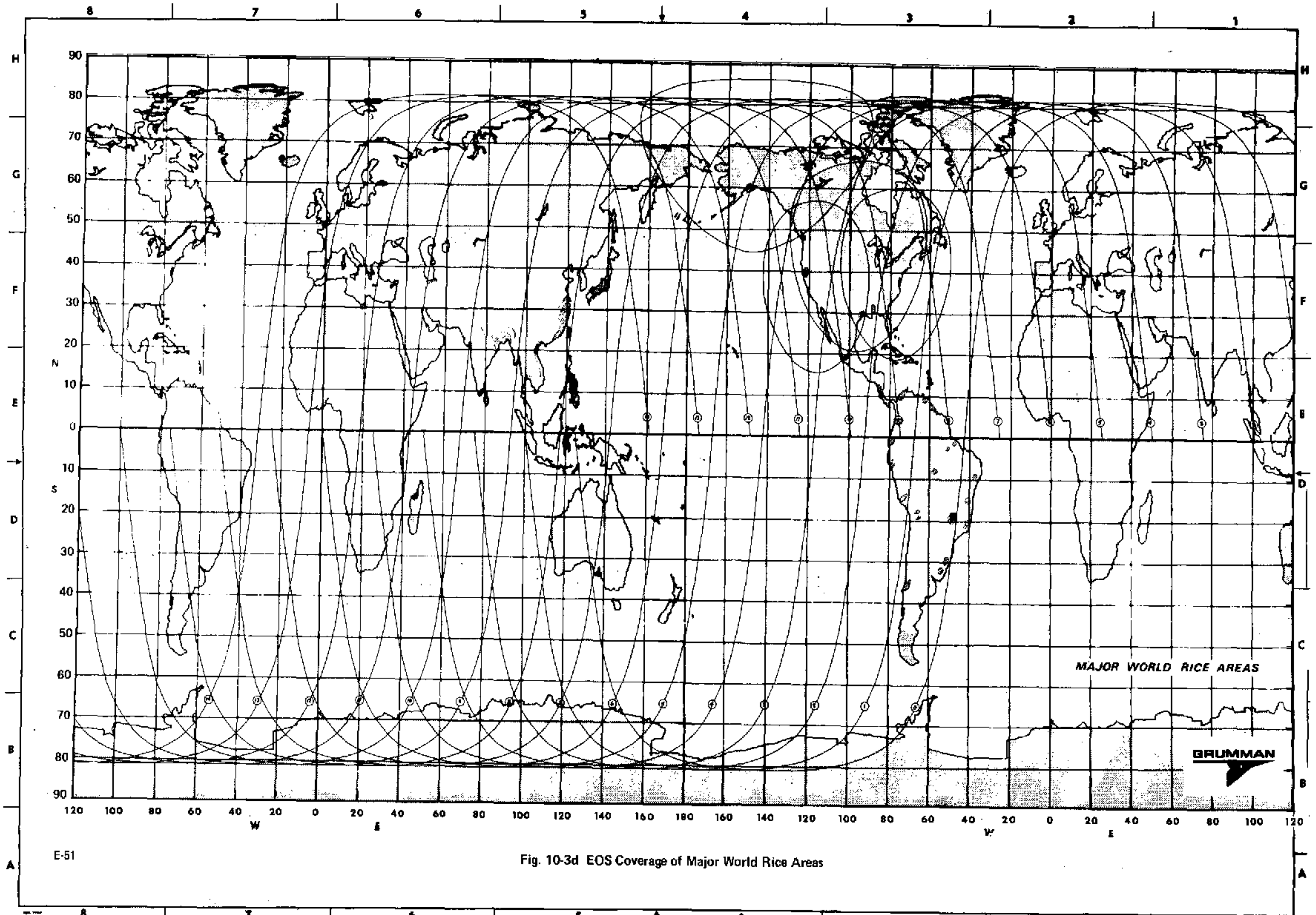
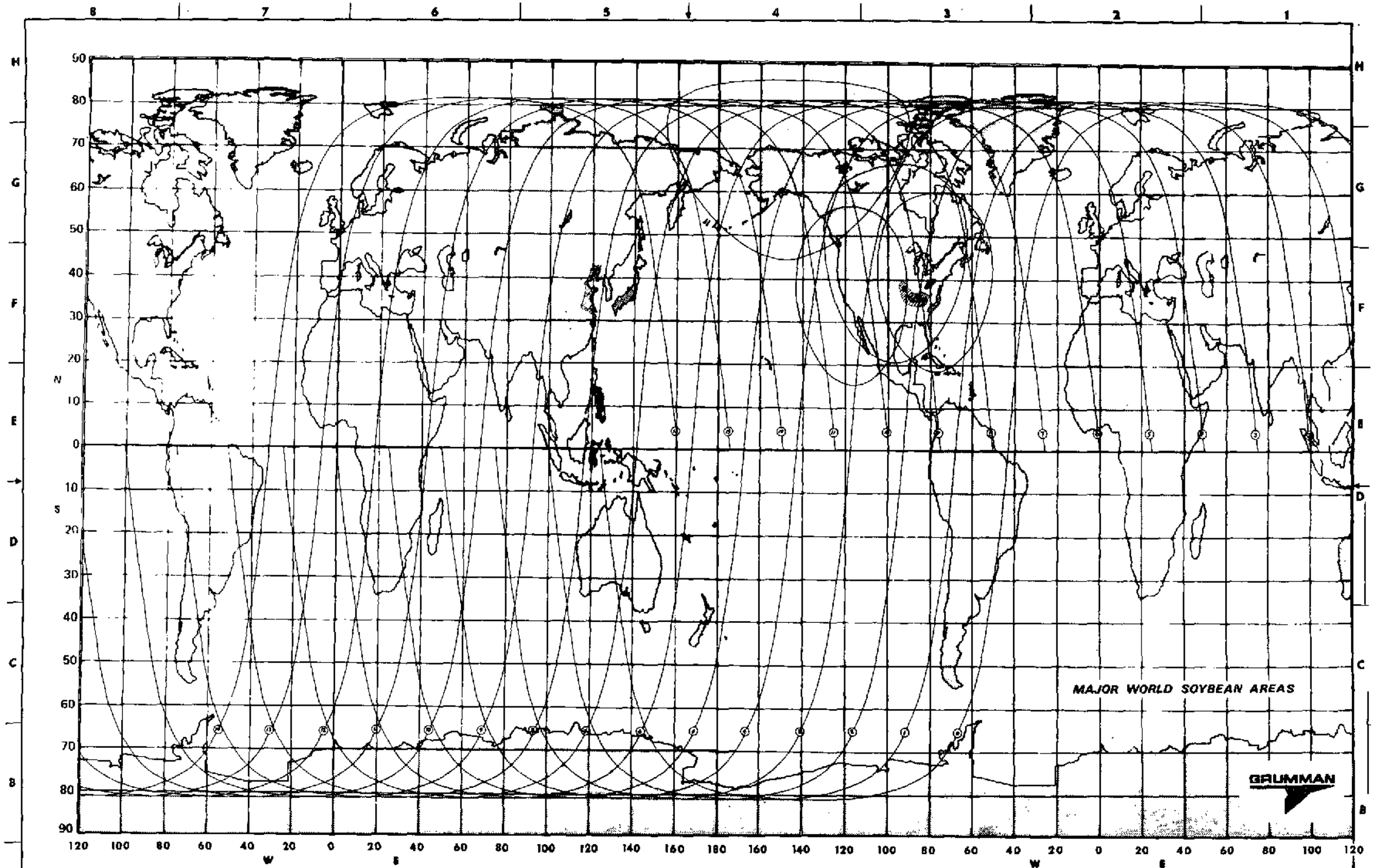
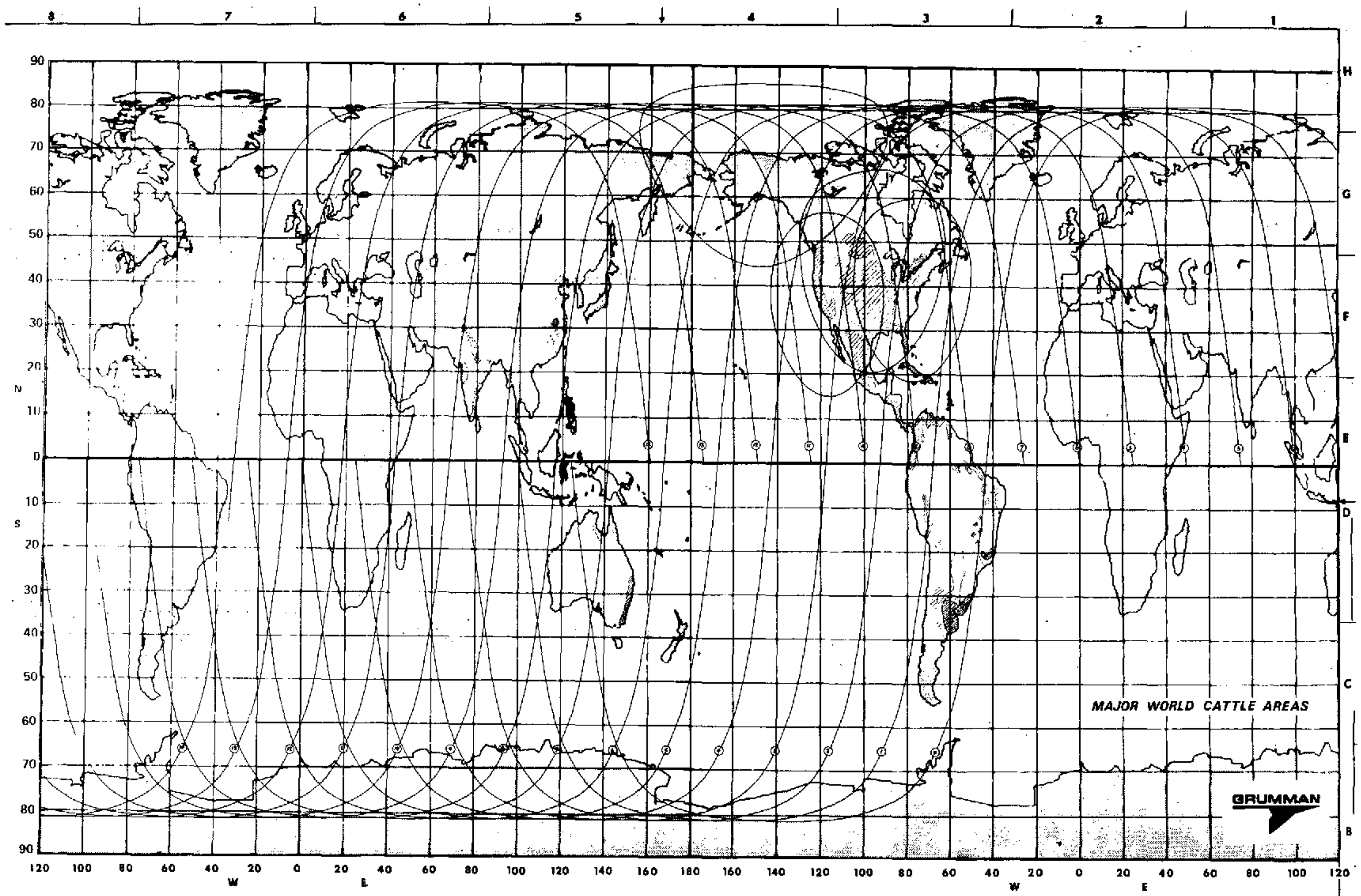


Fig. 10-3d EOS Coverage of Major World Rice Areas



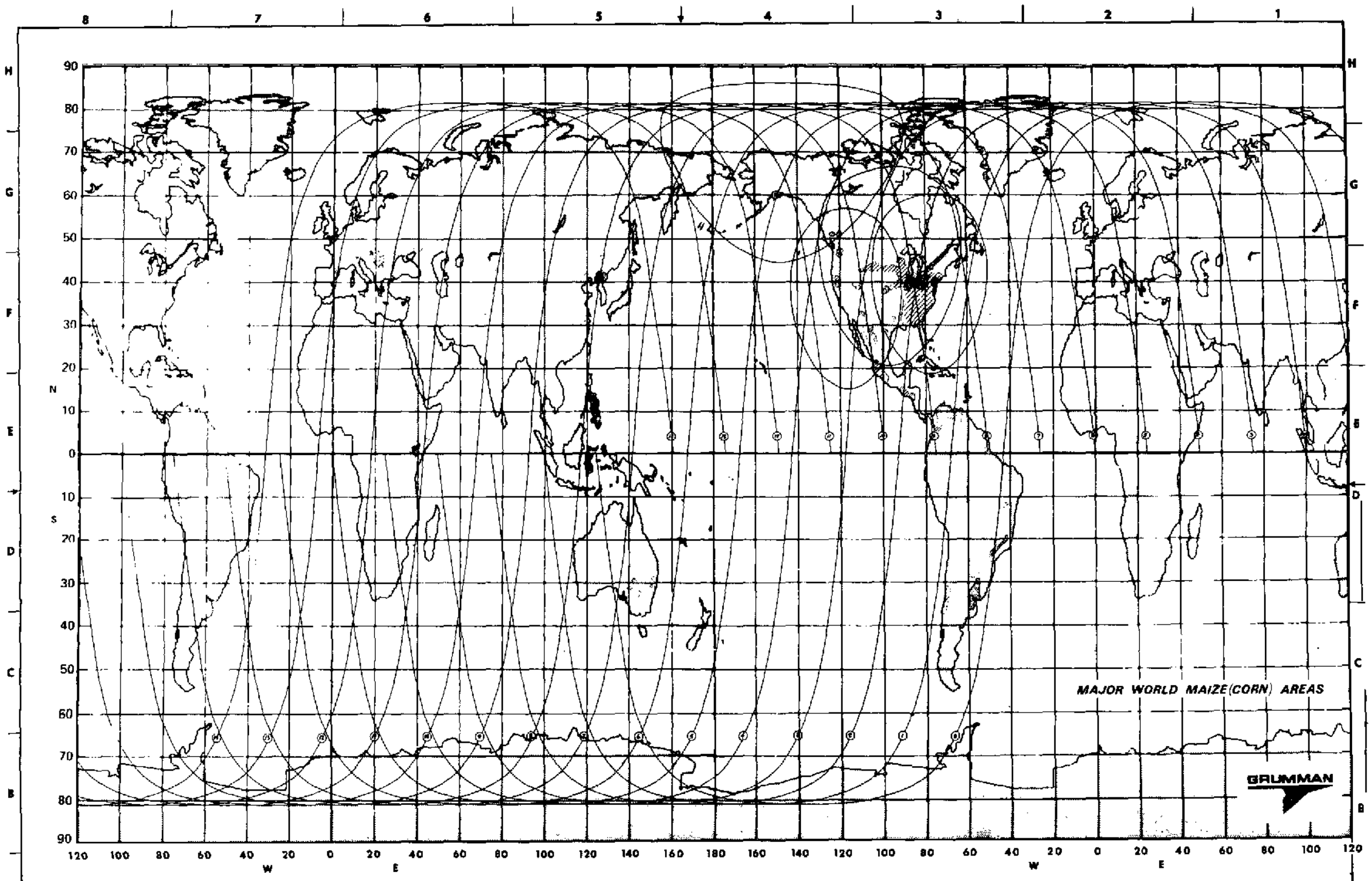
E-52

Fig. 10-3e EOS Coverage of Major World Soybean Areas



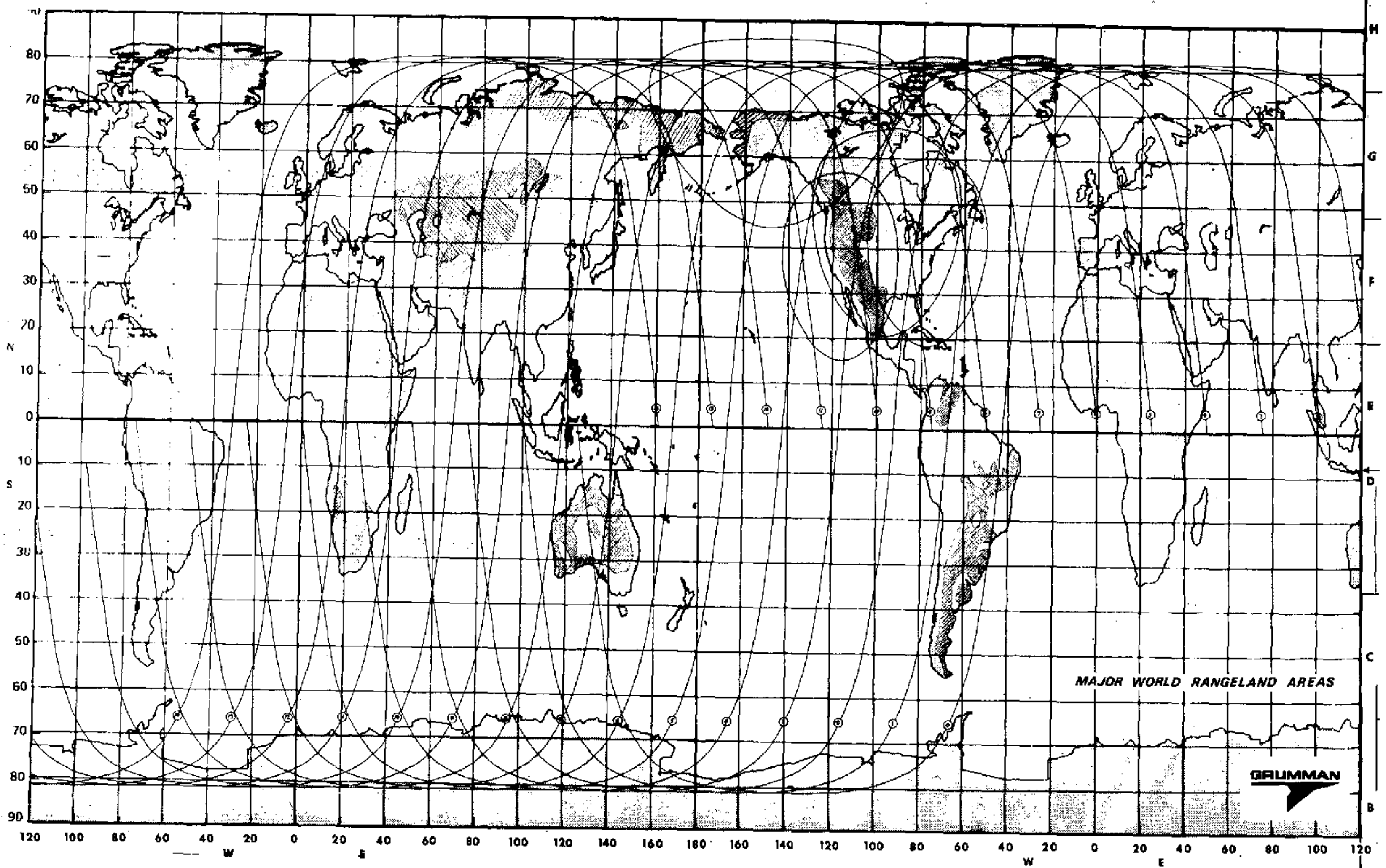
E-53

Fig. 10-3f EOS Coverage of Major World Cattle Areas



E-54

Fig. 10-3g EOS Coverage of Major World Maize (Corn) Areas



E-55

Fig. 10-3h EOS Coverage of Major World Rangeland Areas

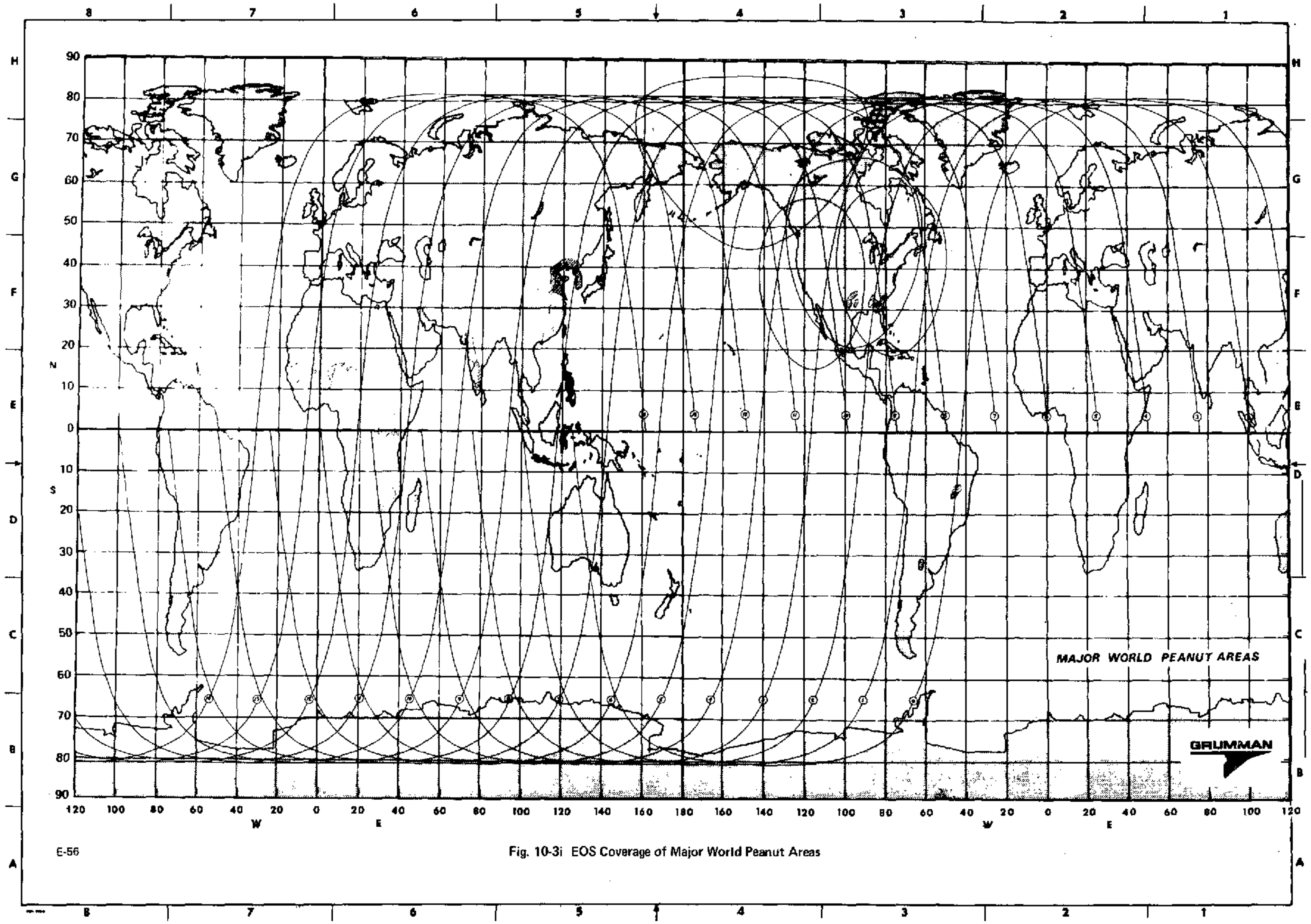


Fig. 10-3i EOS Coverage of Major World Peanut Areas

TABLE 10-7

SCENES PER DAY TO MONITOR THE WORLD'S

MAJOR AGRICULTURAL REGIONS

CROP	TOTAL SCENES	REAL TIME	RECORDED
Wheat	55	15	40
Cotton	105	9	96
Peanuts		4	47
Sorghum & Millet	94	11	83
Maize	110	23	87
Rice	71	6	65
Soybeans	26	5	21
Cattle	207	37	170
Rangelands	264	42	222
*All Major Food Prod. Areas	303	43	260

*NOTE: The same scene will often cover more than one crop. For reference the total world land mass can be covered by approximately 413 scenes per day, 54 real time and 359 recorded.

10.4 Atmospheric and Solar Effects

10.4.1 Introduction:

We have considered the various environmental factors which must be dealt with to design an optimal remote sensing mission. First, we have looked at the effect of solar zenith angle on signal quality. Since we have some leeway in choosing orbit time of day we may select an optimal time for best viewing conditions. Secondly, we have looked at the range of sun angles as a result of choosing a specific time of day and have taken a quick look at signal levels expected in each band as a function of solar angle. From this we have derived a first guess at maximal and minimal signal levels expected over the entire mission. A complex atmospheric model was then employed to take a first look at contrast degradation from the atmosphere and its variations with offset angle. We then studied the various modifications of this model to define our goals for the balance of this study.

In summary we have attempted to address ourselves to the following questions:

1. What orbit time of day is best in terms of user requirements?
2. What is the range of signal levels the detectors will see and what will the contrast levels be like?
3. What is the maximum useable offset angle and what happens to contrast levels as this angle is approached?
4. What radiometric corrections will have to be applied to the data to allow for atmospheric effects?
5. What happens to the contrast levels as the swath width of the instruments is increased?

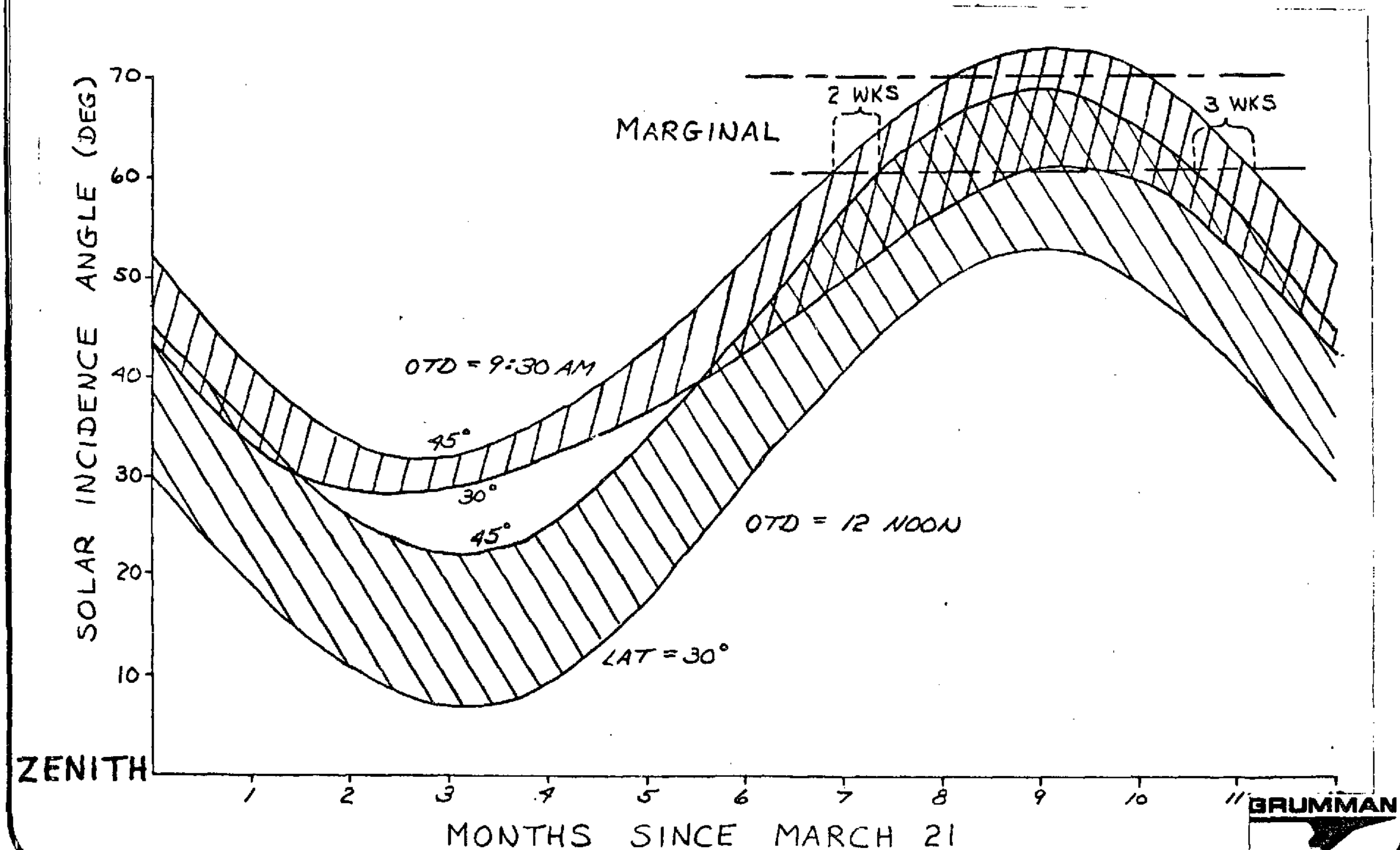
10.4.2 ORBIT TIME OF DAY- SOLAR ANGLE

In general, remote sensing of the earth is best for high solar angles (near Zenith) and becomes increasingly difficult as the sun goes much below 30° from the horizon. The exceptions are those applications for which shadowing is beneficial such as in some geological and cartographical surveys for example. It may be stated that many more user applications will be satisfied by higher rather than lower sun angles. Near noon orbits yield best photometric information (maximum brightness). However, water areas will be affected adversely by sun glint within approximately a 10° cone, while recognition of some types of vegetation is facilitated at or near solar opposition.

The most important factor which limits the range of useful sun angles is the increased shadowing effects that become apparent as the sun goes below about 30°. Target reflectivities will change with phase angle as will the quality of the image seen from space due to increased atmospheric scattering and absorption, but shadowing will be the first effect of importance.

With this as a guideline we may look at the available range of sun angles as determined by the orbit time of day from the point of view of the user. Apart from considerations of local weather and visibility, cloud cover, etc., we may say that the optimal launch time for meeting the greatest number of user requirements will be the one which allows the highest solar elevations. Figure 10-4 shows the seasonal variation of solar angle ranges seen by EOS over CONUS for a 9:30 A.M. and a 12 Noon orbit. The latitudes between 30° and 45° cover most of the CONUS. It is apparent that a near noon orbit will provide good viewing conditions throughout most of the year for much of the U.S., and that a good portion of the U.S. will have a good range of sun angle over the entire year. Naturally those users requiring some amount of shadowing will find that some regions of the southern U.S. will be less than optimal for a good portion of the year. On the other hand a 0930 orbit will provide good viewing conditions for all users over the entire U.S. for about 10 months

FIGURE 10.4 - SOLAR ANGLE VS MINTHS FOR 0930 AND 1200 TIME OF DAY, 30° AND 40° LATITUDE.

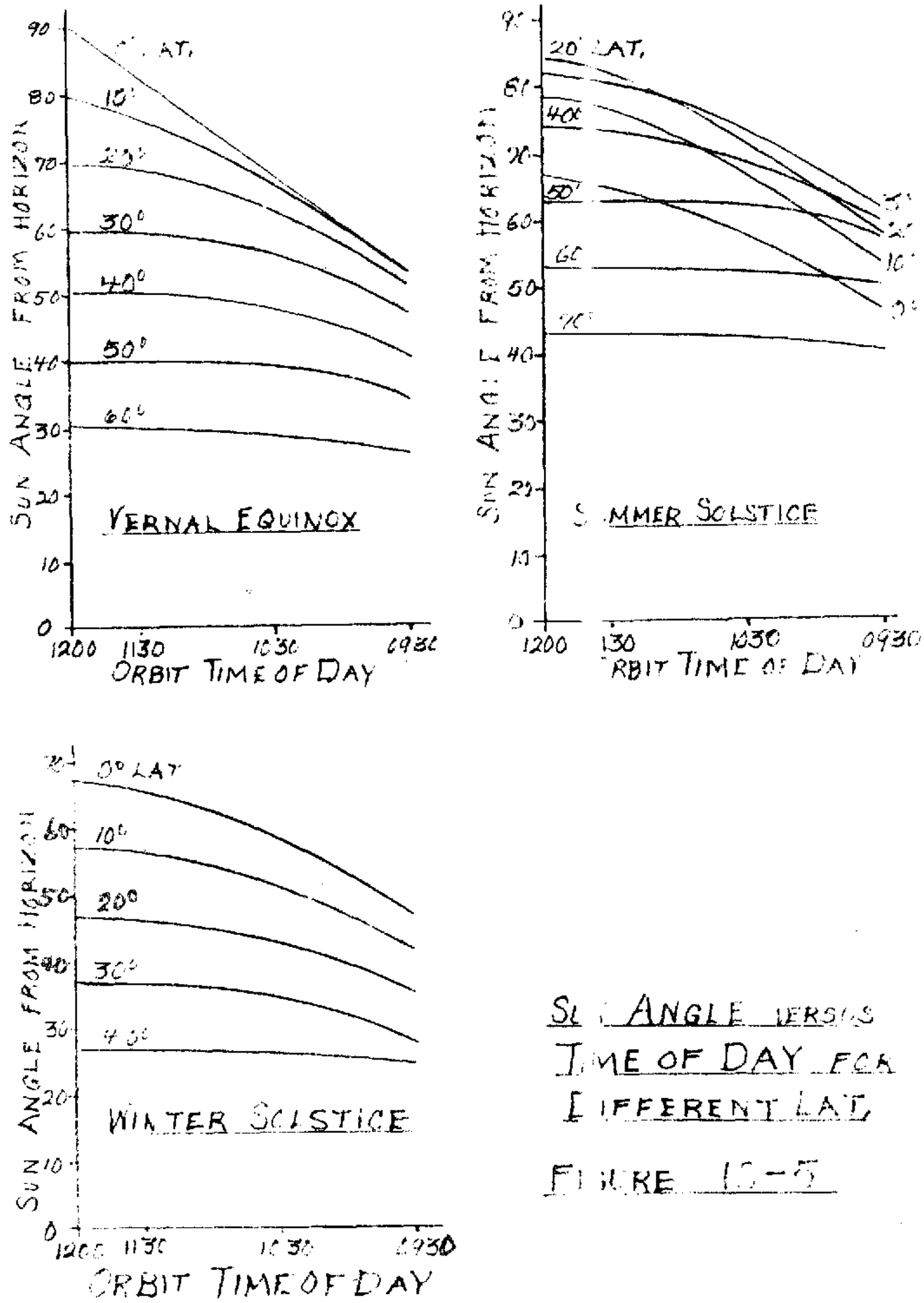


of the year, while for a period of about 2 or 3 months of winter some sections of the U.S. will have rather poor viewing conditions for those users for whom shadowing is not an advantage. If a 30° sun elevation is considered as minimal then a 12 noon orbit gives 5 weeks more of useable coverage for the northern most CONUS than the 0930. Another plot, showing sun angle versus time of day for different latitudes, Fig. 10-5, was prepared to show the impact of time of day on the shape of the sun angle curve at the higher latitudes. Sun angle versus orbit time of day does not change rapidly for low sun angles at high latitudes; however, at lower latitudes nearer noon orbits give significantly higher average sun angles.

Viewing conditions over Alaska are relatively insensitive to orbit time of day and in general there will be low sun angles corresponding to the Alaskan latitude range of 55° to 70°. Thus for example, on June 21 the sun will reach a maximum elevation angle of from 33° to 57° depending on latitude, and on December 21 some regions will be in total darkness throughout the day. In general therefore one may expect less than optimal viewing conditions for a good part of the year over much of Alaska for applications not involving shadowing effects. However, the more southerly latitudes will be available for remote sensing for a good part of the year during clear conditions.

10.4.3 ORBIT TIME OF DAY - CLOUD COVER

Based upon Grumman's experience gained on ERTS-A Experiment #589, in the Virgin Islands we appreciate the problem of cloud build up in many areas of the world during the morning. We obtained from the National Weather Data Center, Asheville, N.C. Summaries of Cloud Cover for 11 stations located



SUN ANGLE VERSUS
TIME OF DAY FOR
DIFFERENT LAT.

FIGURE 10-5

in and around the major agricultural areas of CONUS and also approximately 20 foreign stations near or in agricultural areas. These summaries are cumulative for all years and are based upon 150,000 to 250,000 observations for each of the U.S. stations; hence, the averages shown on Fig. 10-6 can be used to predict with high probability the cloud cover versus time of day for the entire year. The summaries will be further reviewed for the growing season in the major northern hemisphere agricultural areas.

Based upon the U.S. stations; there is some advantage to launching the EOS so that the local time of day approaches 0930. In Fig. 10-6 the overall average of the 11 stations plotted shows 0.55 cloud cover for the period of 0600 to 0800. This increases to 0.585 for 0900 to 1100 period, 0.62 for 1200 to 1400 and then cecreases to 0.594 for the 1500 to 1700 period. Admittedly the advantage is small for CONUS agricultural areas and might not be representative of the world cloud cover situation. This aspect will be clarified for the final report, Oct. 15, 1974.

10.4.4 Orbit Time Of Day - Thermal IR

For many applications the thermal IR period of maximum temperature difference occurs about 1330 and after midnight to dawn, see Figure 10-7. This is due to changes in thermal emission during a diurnal or seasonal cycle. In many cases the thermal emissions of two or more materials undergo a reversal relative to each other during a heating and cooling cycle. These effects can be correlated with geophysical and geothermal properties of soil, moisture, plant stress, marine processes, etc. For maximum utilization of the thermal IR band the orbit time of day should be about 1330.

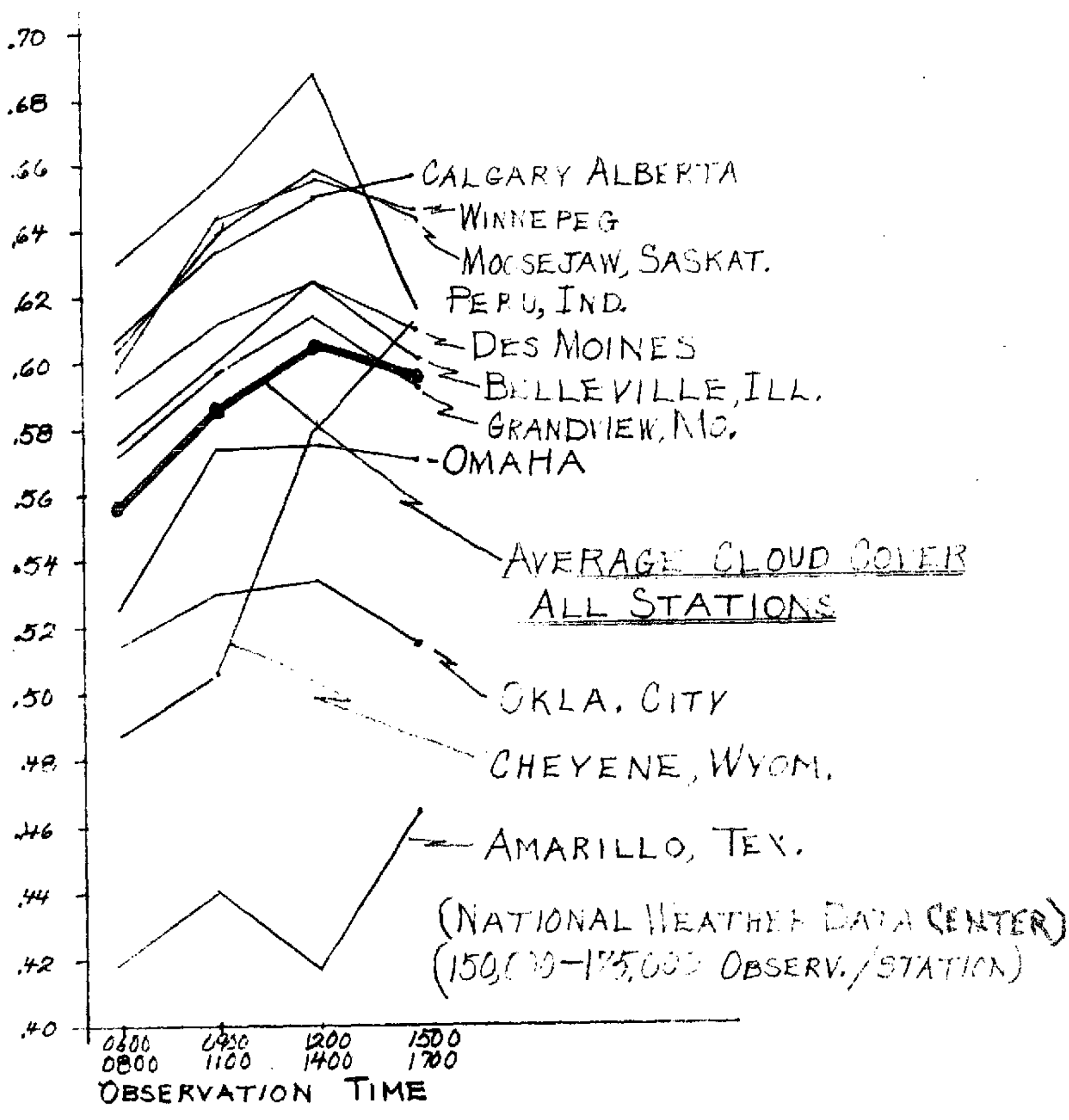
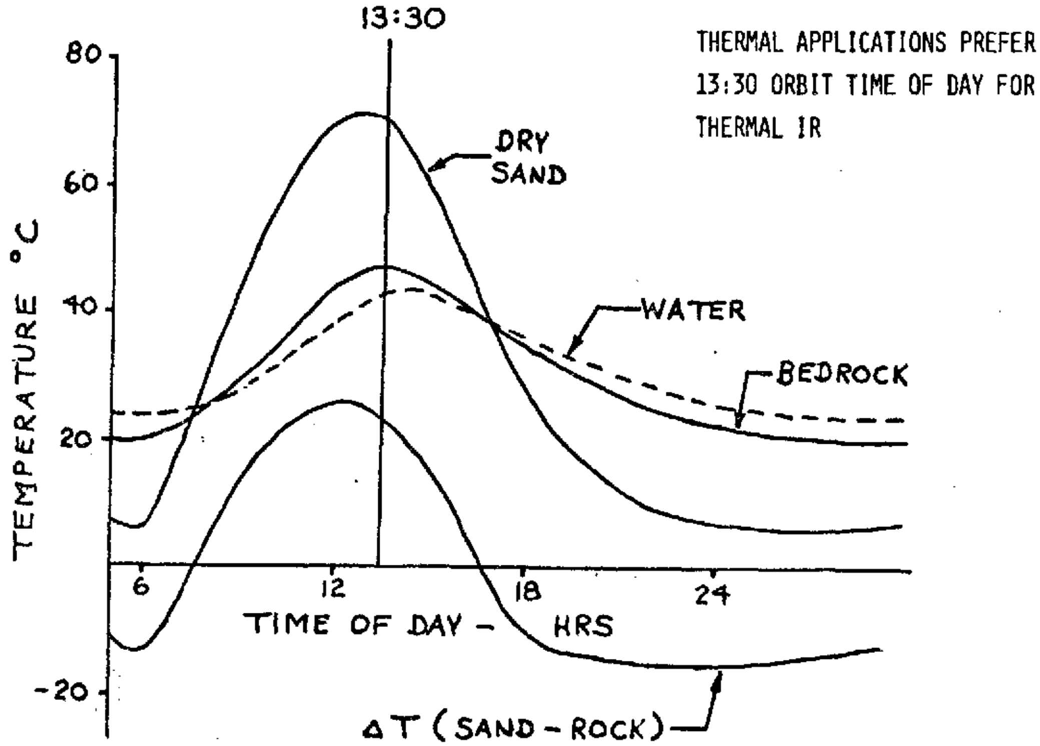
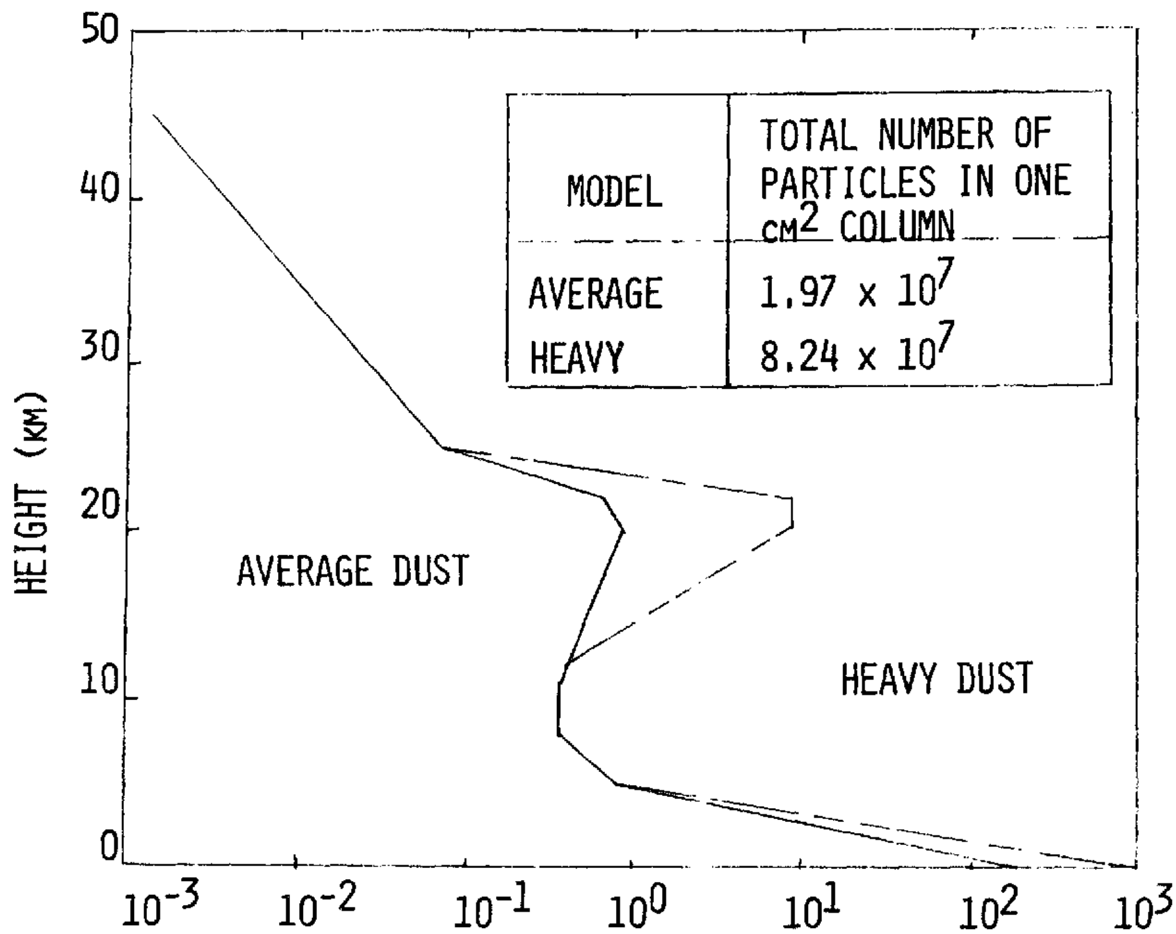


FIGURE 10-6 CLOUD COVER N. AMERICAN AGRICULTURAL BELT



DIURNAL SURFACE TEMPERATURE VARIATION

FIGURE 10-7



PARTICLE NUMBER DENSITY (cm^{-3})
AVERAGE AND HEAVY DUST CONDITIONS
FIGURE 10-8

10.4.5 ATMOSPHERIC EFFECTS ON REMOTE SENSING

Photometric remote sensing of the earth from space requires an understanding of the effects of the intervening atmosphere on the quality of the images seen at the detector. Atmospheric scattering and absorption including the effects of various aerosols serve to modify the level of solar illumination reaching the ground and tend to reduce target versus background contrast levels as seen from space. The latter is a result of both the reduction of target light by absorption and scattering out of the line of sight and the scattering of nontarget light into the field of view.

10.4.5.1 Aerosols, and Their Effect

In Figure 10-8 are shown the aerosol height distributions for two different atmospheric particle loadings. The "average dust" distribution corresponds to clear sky conditions, while the "heavy dust" corresponds to severe atmospheric loading.

In the range of wavelengths between 0.3 and 2.5 μm, the effect of the heavy dust loading, shown in Fig. 10-8, is to increase both the scattering and the absorption by a factor of about 2. Thus, the heavy dust loading decreases the ground irradiance in this wavelength range by a factor of about 2.

The concentration of aerosol constituents in polluted areas varies daily, weekly and seasonally. These variations are the result of the interaction between the rate of production and the rate of dispersion, the latter being a complex function of the meteorological conditions and the topography.

The production rate of most pollutants is highest near highly industrial and populated areas, having a minimum during the night, augmented by settling out during the night. Situations can also exist where dust from Sahara desert storms may be blown as far west as the Carribbean to lower the visibility.

10.4.5.2 ATMOSPHERIC ATTENUATION

The total downward irradiance at ground level derives from two sources, direct solar radiation and diffusely scattered sky background radiation. In a clear atmosphere the direct solar component varies very slowly with sun angle as the zenith angle goes from zero to about 40° and drops to about 50% of maximum at 60° following an approximate cosine law. The contributions from sky background vary very slowly with zenith angle and are assumed independent of angle down to 10 or 20 degrees from the horizon for our calculations. As may be expected the angular dependence of direct illumination is even less for decreased visibility conditions since more scattering takes place. An important factor contributing to sky background intensity is the average ground reflectivity which varies with the targets of interest. Thus for example sky brightness may be expected to be considerably greater in regions of extended snow cover than say over a body of water where the reflectivity is only a few percent.

In order to obtain a first estimate of the range of luminosities seen by the spacecraft in each spectral band we employ a simplified atmospheric model based on some ERTS measurements analyzed in Reference 2. In general the signal L seen outside the earth's atmosphere from a spacecraft looking at the nadir can be written as

$$L = \frac{\rho H \tau}{\pi} + L_{Path} \qquad (1)$$

where H is the target irradiance, τ is the atmospheric transmittance, ρ is the target reflectance and L_{Path} is the non-target light scattered into the field of view. The functional form of the target irradiance, H, is given by:

$$H = H_o \tau^{\sec\theta} \cos\theta + H_{sky} \qquad (2)$$

where H_o is the solar constant (Ref. 6) θ is the solar zenith angle and H_{sky} is the diffuse component of irradiation. Rogers and Peacock measured τ, L_{Path}, and H_{sky} in the ERTS bands 4, 5, 6, 7 corresponding to EOS bands 1, 2, 3 and 4 respectively, for a sun angle of 49° in Ann Arbor, Michigan on 28 September 1972. For a first approximation we will assume these measured quantities are reasonably representative of average viewing conditions of a particular area, and attempt to trend the data for other sun angles to get an idea of the range of illumination levels to be expected in each band.

Strictly speaking these expressions apply only for monochromatic radiation of wavelength λ , but to a good approximation the expressions may be integrated over $\Delta\lambda$ the pass band of the detectors and divided by $\Delta\lambda$. The path radiance seen by the detectors is also a function of scan angle; i.e., wider scan angles accept more stray light. For the initial estimates of these quantities we will make a narrow scan angle approximation to obtain some rough estimates of the instrument performance. It should be noted that for large scan angles such as for the wide angle MSS, considerably more stray light can reach the detectors than for a narrow angle system. This phenomenon will receive closer attention in the final report.

TABLE 10-8
ERTS DATA FOR BRIGHTNESS CALCULATIONS

EOS BAND	L_{PATH}	Ho (mw/cm^2)	τ	H_{sky} (mw/cm^2)
1	0.274	19.72	0.810	1.25
2	0.118	16.73	0.865	.787
3	0.082	12.98	0.909	.573
4	0.1062	25.01	0.913	.126

Table 10-8 contains the basic data derived from the ERTS measurements. The target of interest was a pond in a low lying area near Ann Arbor. These data were used to derive reflectivities for the target area in each band. Table 10-9 gives the radiance levels measured and the derived values of spectral reflectivity.

TABLE 10-9

ERTS MEASUREMENTS OF TARGET RADIANCE

EOS BAND	TARGET REFLECTIVITY(%)	MEASURED RADIANCE (mw/cm^2 - ster)
1	9.3	0.476
2	5.5	0.242
3	2.8	0.141
4	0.9	0.234

For clear sky conditions, H_{sky} varies very slowly with θ for solar elevations above 40° and we will assume it to be constant with θ for our calculations. Actual values for H_{sky} for low sun angles should be somewhat less so that our estimates of minimum target radiances are likely to be a bit on the high side, but not by very much. We will also assume that the L_{path} values at $\theta = 49^{\circ}$ are the same as for $\theta = 0^{\circ}$. Some justification for this assumption is given by Duntley (Reference 3) who has measured broadband values for path radiances from aircraft. Measurements were taken for 3 sun angles, 20°, 42.5° and 65° and are presented in Table 10-10.

TABLE 10-10

PATH RADIANCE VERSUS SOLAR ANGLE

Solar Zenith Angle	Green Sensor (ft-L)	Red Sensor (ft-L)
20°	308	0.0378
42.5°	318	0.0354
65°	184	0.0226

Using equation (1) we now derive maximum radiance levels corresponding to $\theta = 0^o$ and ρ = 100%, and the measured values of atmospheric transmittance τ from Table 10-8. For comaprison in Table 10-11 we present estimates of maximum useable radiance levels expected, corresponding to a sun angle of 0^o and ground level reflectivities of 100% and 75%.

TABLE 10-11

THERETICAL MAXIMUM RADIANCE LEVELS FOR EOS

BAND	L_{max} (mw/cm^2 - ster) ρ = 100%	L_{max} (mw/cm^2 -ster) ρ = 75%
1	4.71	3.60
2	4.32	3.27
3	3.66	2.77
4	6.78	5.11

If we restrict the problem to that of finding the probable maximum radiance levels we must examine the range of likely targets and lighting conditions. A reasonable guess would be snow cover in Colorado in late spring. This combines a maximum reflectivity of 95% for snow with a moderately high sun angle.

From Fig 10-4 we see that for a 0930 orbit around mid-May we may expect a 60^o sun elevation and from our simplified model we obtain the corresponding radiance levels as shown in Table 10-12.

TABLE 10-12

PROBABLE MAX RADIANCE LEVELS

EOS BAND	0930 ORBIT $\theta = 30^\circ$ $\rho = 95\%$	12 NOON ORBIT $\theta = 20^\circ$ $\rho = 95\%$
1	3.86	4.21
2	3.53	3.85
3	3.01	3.27
4	5.52	6.03

For a 12 noon orbit the sun angle would be more like 70° in elevation and we obtain the correspondingly higher maximum levels shown in Table 10-12. ERTS measurements on Experiment No. 589, performed by Grumman personnel, indicate that these estimates are not unreasonable.

Estimates of minimum useable radiance levels are a function of what one assumes for minimal useable lighting conditions. Sun angle elevations as low as 5° or 10° above the horizon are representative of northern Alaskan latitudes seen by EOS in mid winter. However, most of the ground area will likely be snow covered and hence have high reflectivity. If we take the case of water with a reflectivity of 4% as seen with a solar zenith angle of 70° as more representative of minimal lighting conditions over conus we obtain minimum radiances as shown in Table 10-13. Here we have used Duntley's estimate of about a 1/3 reduction in path radiance at 65° compared to 20° solar zenith angle. For comparison we present estimates of radiance levels in Alaska for $\theta = 85^\circ$ with a ground reflectivity of 10% in all bands. In any event it appears that the NASA specifications for minimum radiance levels are higher than the calculated values; i.e., for some cases viewing will be instrument limited.

TABLE 10-13

PROBABLE MINIMUM RADIANCE LEVELS (mw/cm²-ster)

EOS BAND	CONUS $\theta = 70^{\circ}$ $\rho = 4\%$	ALASKA $\theta = 85^{\circ}$ $\rho = 10\%$	NASA SPEC.
1	.234	.220	.22
2	.129	.108	.19
3	.100	.082	.16
4	.149	.097	.30

10.4.6 COMPUTERIZED ATMOSPHERIC MODEL

Realizing that our first approach makes some rather broad assumptions regarding atmospheric transmissivity, path radiance, sky brightness, etc, we have attemped to employ a computerized atmospheric model which takes into account more realistic atmospheric profiles and calculates atmospheric scattering and absorption with considerably more accuracy. As a first attempt at using this model we have employed only one standard atmospheric model and have not attempted to vary atmospheric and aerosol profiles. The range of problems was restricted for this first attempt, and a wider approach will be employed and presented for the final report. Effects of variations in atmospheric, aerosol, and local conditions (such as air polution, etc.) and visibility will be looked into. For simplicity the AFCRL Standard Atmosphere (Ref. 1) was assumed as typical, however this was later found to be quite optimistic since ground visibilities are often less than that assumed for the model.

10.4.6.1 Dave-Braslau Atmospheric Scattering Program - In order to determine the effect of aerosols on the solar energy absorbed, reflected and transmitted by a cloudless, homogeneous atmosphere, a mathematical model good to 0.5% accuracy was employed (Ref. 5). This model permits variations to be made in the aerosol concentration (spherical particles with size distribution and refractive index independent of height) and in the ozone and water vapor in 160 layers of varying thickness from the earth's surface to 45 km altitude. While 45 km is considerable less than the EOS altitude, the results obtained from the model serve as a good initial approximation. Upward and downward light fluxes are computed in the wavelength range from 0.285 to 2.5 μ taking into account all orders of scattering. The wavelength dependence of the optical complex index of refraction is taken into account in the calculations.

The calculations also take into account the solar zenith angle and a range of Lambert ground reflectivities. From these calculations, contrast degradation may be deduced for various targets. The basic computer program for these calculations was developed by Dave and Braslau of IBM. We have adapted the program to our needs, and have developed laboratory techniques to determine the optical complex indices of refraction necessary for the program.

TABLE 10-14

Contrast Reduction Effects

(deduced from Dave-Braslau atmospheric scattering model)

Light Wavelength = 0.550 μ um

Sun Zenith Angle = 40 degrees

Altitude = 75 km

AFCRL midlatitude summer atmosphere

Target	HRPI Contrast Nadir	HRPI Contrast $+46^{\circ}$	HRPI Contrast -46°	Ground Contrast
Black vs. White	17.70	13.85	9.64	∞
Average Shore Line vs. Water	8.07	6.89	5.35	19.00
Farm Land vs. Potato Crop or Sugar Maple vs. Red Pine Trees	.625	.567	.474	1

TABLE 10-15

Contrast Transmittances for above Targets

	Nadir	$+46^{\circ}$	-46°
Average Shore Line vs. Water	.425	.363	.282
Farm Land v vs. Potato Crop or Sugar Maple vs. Red Pine Trees	.625	.567	.474

We use the standard definition of contrast level as seen at a distance R of target versus background as,

$$C_R = \frac{B_T(R) - B_B(R)}{B_{B(R)}}$$

where

B = brightness in watts/cm^2-steradian

Subscripts T, B = target and background respectively.

Contrast transmittance is defined for a specific set of viewing conditions (look angle, distances from target, etc.) and is the ratio of the apparent contrast seen by the instrument to the contrast at ground level.

TABLE 10-16

Contrast Transmittance for 100%/4% and 20%/10% Reflectance

Band	Wavelength(μ)	Approx. Absorbed Radiation(%)	Approx. Scattered* Radiation(%)	Contrast 100/4%	Contrast 20%/10%
1	.5-.6	20	5	8.5	1.5
2	.6-.7	10	3	11.8	.77
3	.7-.8	2	1	19	.65
4	.8-1.1	5	1	18	.60
5	1.55-1.75	2	0	24	.96
6	2.1-2.35	2	0	24	.96
7	10.4-12.6	30	0	17	2.0

*i.e., scattered out of the line of sight.

The contrast in the table above is seen to improve with increased wavelength for a 100% reflecting shore against a 4% reflecting body of water. The reason for this is that the atmospheric scattering decreases approximately inversely with the fourth power of the wavelength. Since the program only calculates up to 2.5μ, contrast transmittances for band 7 were calculated by hand, assuming an atmospheric transmittance of 80% and zero path radiance. Atmospheric emission was also assumed to be negligible. The high absorption in band 7 is the result of water vapor in the atmosphere. To a first approximation, the effect of the atmosphere is to degrade the temperature resolution of band 7 to about 3/4 degree at 300°K but this result is only approximate and will be refined for the final report.

10.4.7 Radiometric Corrections Over the Field of View

In our simplified first approach to atmospheric corrections we have used some rather broad approximations to get an idea of what the numbers are like without getting involved in more extensive computerized modeling. One such approximation has been the assumption of a narrow swath width. In particular the question of variation of atmospheric and solar lighting conditions across the field of view was not addressed.

In order to take full account of large swath widths corrections must be made for

1. variations in atmospheric thickness across the field of view including allowances for variations in haze, water droplets, and dust distributions
2. variations in sun angle
3. variations in average ground reflectivity. This effects the overall level of diffuse illumination from sky background.
4. radiometric corrections for variations of target reflectance with viewing angle (the status of these corrections is more tenuous).

There is some indication that these corrections were minimal for the ERTS-1 MSS (Ref. 4) where the total scan angle was only 11^{o}. However, for offset pointing, for wider scan angles, and for greater spatial resolution these corrections will have to be looked at more closely. More precise computerized modeling is available and will be employed in the latter part of the study to examine the extent of these corrections. Results will be included in the final report.

10.4.8 Aurora and Airglow

Aurora and airglow offer no problems to visual or infrared observations ove Alaska or CONUS. Although there are airglow emissions over these regions they are at least three orders of magnitude below the brightness of the aurora in the Northern Hemosphere. The airglow can be caused by atomic oxygen, the ion OH^-, sodium, or atomic nitrogen. In contrast to airglow, auroral emissions are ordinarily observed only from the middle and high latitudes. However the brightness is at least three orders of magnitude below the brightness of a clear blue Rayleigh scattering sky, and even less bright compared to clouds.

10.4.9 References:

1. Valley, S.L., Ed., (1965), Handbook of Geophysics and Space Environments, AFCRL.
2. Rogers, R.H. & Peacock K., "A Technique for correcting ERTS Data for Solar & Terrestrial Effects", Symposium on Significant Results Obtained From ERTS-1, GSFC, New Carrollton, Md., March 1973 NASA SP-327, pp 1115-22.
3. Duntley, S.Q., "Interaction of Optical Energy with the Atmosphere" AIAA paper No. 70-288, AIAA Earth Resources Observations & Information Systems Meeting, Annapolis, Md. Mar 2-4, 1970.
4. Sharma, R.D., "Enhancement of Earth Resources Technology Satellite & Aircraft Imagery Using Atmospheric Corrections", VII International Symposium On Remote Sensing of the Environment, Ann Arbor, Mich, 1971.

5. Dave, J.V., and Mateer, C.K. 1967, "A Preliminary Study on The Possibility of Estimating Total Atmospheric Ozone From Satellite Measurements", Journal of Atmospheric Sciences, 24, pp 414-427 (1967).

6. Allen, C.W., Astrophysical Quantities, Athlone Press, 2nd Edition, London, 1963.

SYSTEM TRADE
STUDY NO. 11

TITLE	TRADE STUDY REPORT NO. 11
11. UTILIZATION OF CONTROL CENTER PERSONNEL (UCCP)	WBS NUMBER 1.2.1.3.4

11.1 Introduction

During the course of this study the emphasis in the mission operations areas has been on identifying areas of cost and cost tradeoffs. The overall requirements for EOS operations are derived from the basic nature of the mission and these are presented in Figure 11-1 Payload data processing and data product generation are handled in a facility separate from the Mission Operations Control Center. There are three sections following which describe the Mission Operations Effort:

Section 11.2 - This section describes the baseline functional operation of the MOCC, and its interfaces with external areas, with particular emphasis on the interface with the Central Processing Facility and the Information Management System. Figure 11-2 represents the MOCC functional operation as reflected in the text of Section 11.2

Section 11.3 - This section defines the baseline hardware design for the MOCC. Figure 11-3 is a top level schematic for the MOCC. A detailed hardware list has been prepared and costed. Our baseline hardware approach is centered around a modular grouped mini approach, using standardized display and control features.

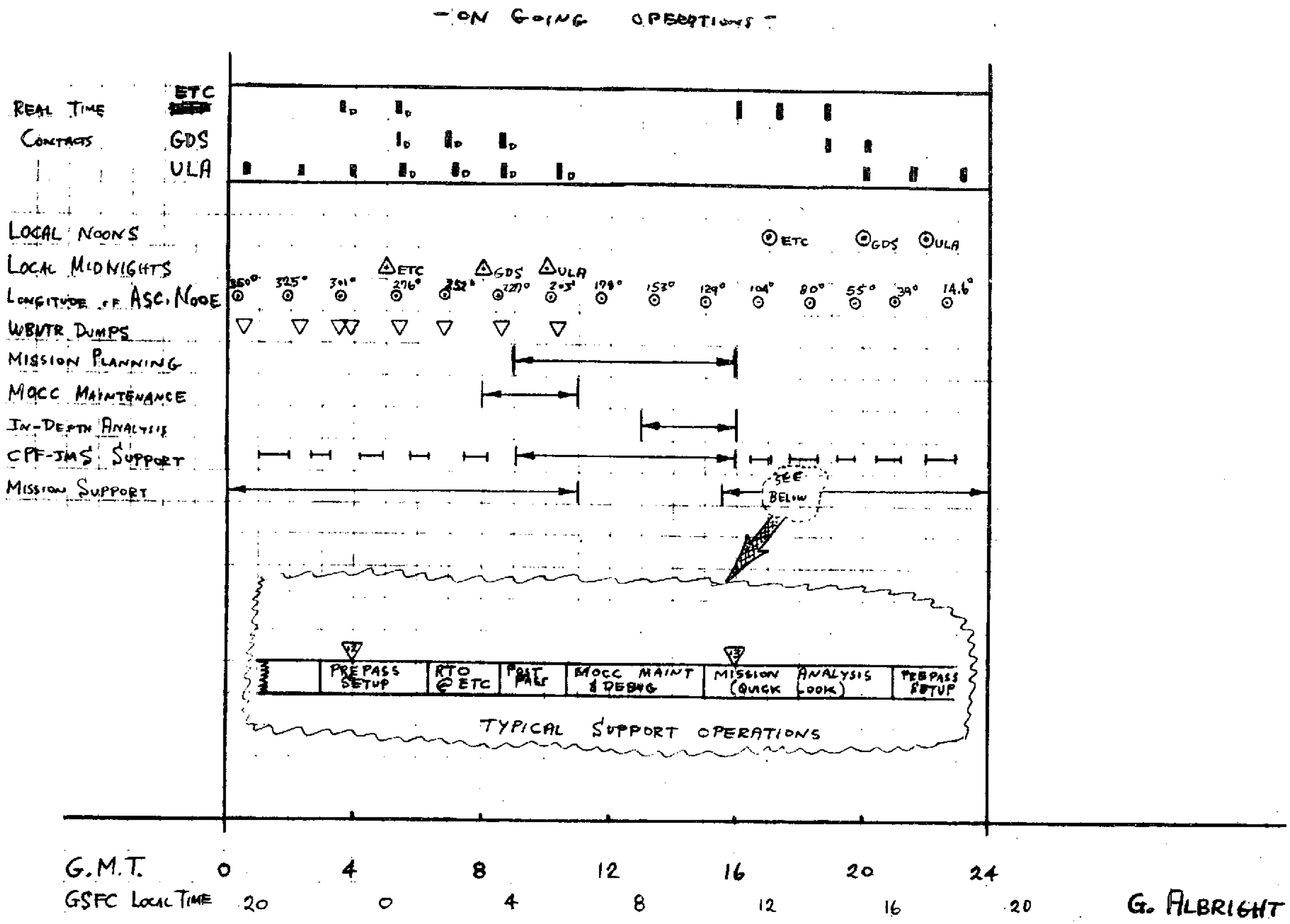


Fig. 11-1 MOCC Time Line

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Section 11.4 - This section shows the manpower requirements for implementing the MOCC concept. These requirements are given in two areas:

(a) The pre-launch phase during which the MOCC is designed and developed, the software is developed, and detailed mission planning is performed.

(b) The on-going operational phase which starts at launch and continues for the life of the spacecraft.

11.2 MOCC Functional Diagram

The functional diagram (Figure 11-2) for the EOS MOCC is structured around the operational flow of the EOS mission. The diagram is oriented as follows:

- o The EOS S/C is the upper left
- o The Central Processing Facility- Information Management System is on the right hand side
- o NASA-GSFC supporting activities (orbit determination, SCPS support, and MISCON) are the bottom
- o The large rectangular section in the middle area of the diagram represents MOCC computing capability. This software may be centralized in a midi computer or decentralized in a grouped mini configuration. Hardware considerations will be discussed in Section 11.3

In terms of data being taken at the STDN sites, only housekeeping data comes into the MOCC. Payload data will be sent directly to the CPF-IMS, and EOS tracking data goes directly to the NASA-GSFC orbit determination facility.

The mission operations effort is divided into three phases:

- o Planning
- o Execution
- o Analysis

These operational phases are discussed in the following paragraphs.

Mission Planning

A large part of the mission planning activity is centered around the MOCC-IMS buffer, which is a disk file giving common access to both the MOCC and the CPF-IMS. (certain portions of the file will be guarded in terms of write capability, and since this file is of critical importance in carrying out operations in both the CPF-IMS and the MOCC it will be heavily protected)

The mission planning operation actually starts over in the IMS area where EOS users initiate their data requests.

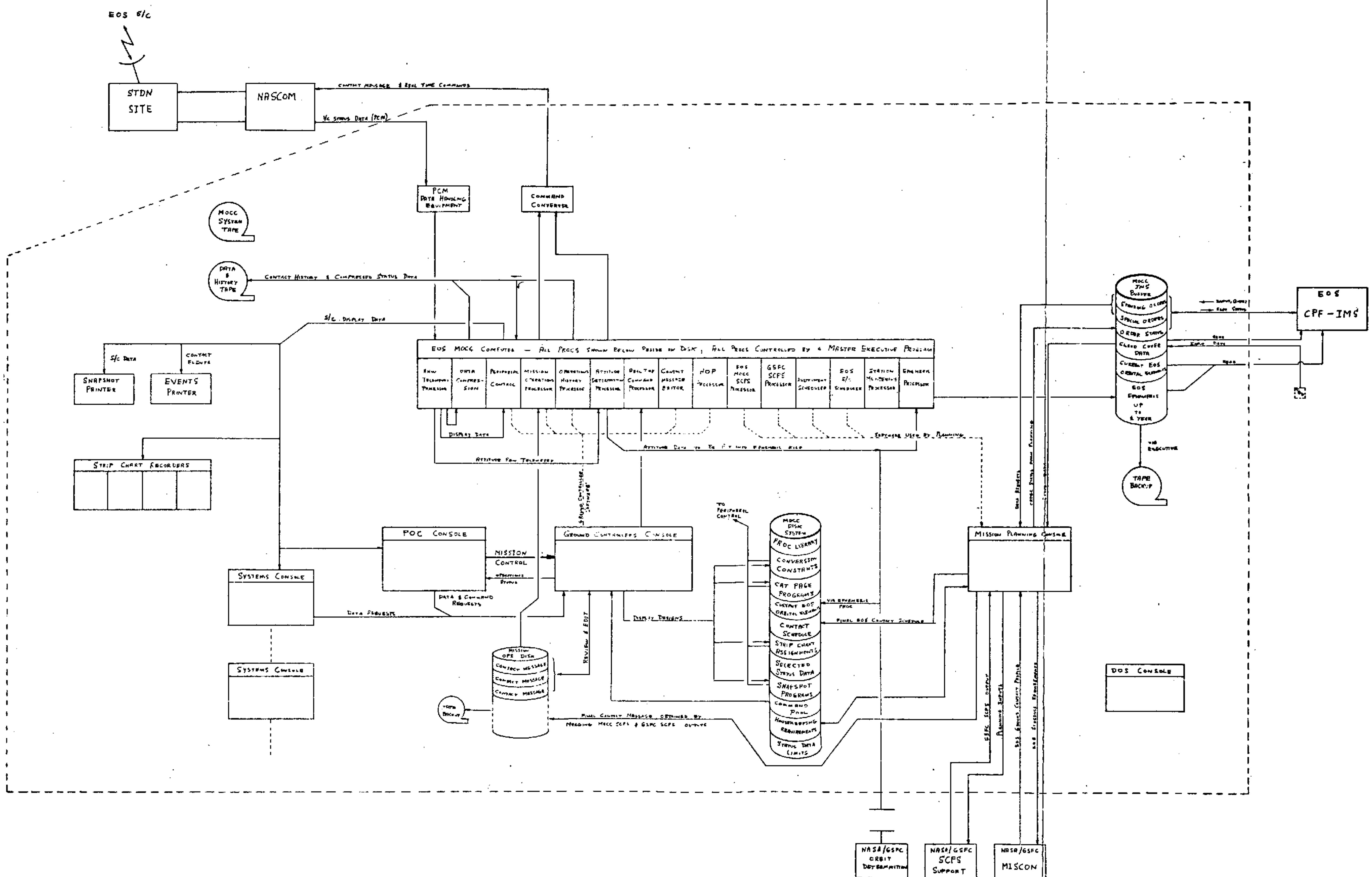

Figure 11-2 EOS Mission Control Center Functional Diagram

There are two types of requests:

- o Standing orders - requests for repetitive viewing of certain areas.
- o Special orders - requests for "single shot" viewing of selected areas.

Both of these requests are fed into the MOCC-TMS buffer for action during the planning phase. Since the readout process is non-destructive, standing orders only have to be entered once.

During the course of mission planning and execution the status of the response to these data requests will be fed into the MOCC-IMS buffer to handle user queries via the IMS.

The cloud cover data in the MOCC-IMS buffer is used for both planning and analysis purposes. The source of this data is yet to be determined, but there are several possibilities at present:

- o Standard NOAA weather forecasts
- o Nimbus spacecraft data
- o SMS data

The current EOS orbital elements are placed in the MOCC-IMS buffer for the purpose of planning activities within the IMS. The EOS ephemeris file is a catalog of the most accurate positions available for the EOS versus time. This data is used in the processing of payload data, and it will be supplied via standard channels from the NASA/GSFC orbit determination group. It is important to realize that orbit prediction is of critical importance to the EOS, and it is for this reason that it is being done outside of the CPF area at the standard GSFC facility. The spacing of the ephemeris points must be close enough to allow the CPF to make accurate interpolation between these ephemeris points via very simple orbit propagation techniques. Table 11-1 shows a comparison between a rapid, pure Keplerian orbit propagation and a more time consuming but sophisticated propagation technique.

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Table 11-1

RSS DIFFERENCE BETWEEN PURE KEPLERIAN AND PRECISION* TECHNIQUE FOR ORBIT PROPAGATION		
Time in Seconds	Position RSS Delta in feet	Velocity RSS Delta in ft/sec
15.000	7.660	1.02[illegible]
30.000	30.639	2.042
45.000	68.924	3.063
60.000	122.508	4.083
75.000	191.368	5.101
90.000	275.483	6.119
105.000	374.822	7.134
120.000	489.352	8.148
135.000	619.034	9.150
150.000	763.822	10.169
165.000	923.66[illegible]	11.176
180.000	1098.517	12.190
↓	↓	↓
540.000	9580.702	34.873
555.000	10101.266	35.744
570.000	10634.151	36.608
585.000	11179.226	37.466
600.000	11736.362	38.316

* The precision technique for orbit propagation is a Cowell type Runge-Kutta numerical integration incorporating the effects of zonal harmonics J2, J3, and J4. No air drag, no sun or moon effects, no radiation pressure.

Semi-major axis = 3810. n.m.
Eccentricity ≐ 0.0
Inclination = 98.0 degrees
R.A. of asc. node = 0.0 degrees
Argument of perigee = 0.0 degrees
Mean anomaly = 90.0 degrees

PREPARED BY	GROUP NUMBER & NAME	DATE	CHANGE LETTER
G. Albright			
			REVISION DATE
APPROVED BY			PAGE 11-5

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The discussion of mission planning now shifts to the Mission Planning Console. This is the station where the overall coordination of the planning activity takes place. The operations at this console are described as follows:

(a) There is an interface with NASA/GSFC MISCON for the process of determining the ground contact profile for the EOS. The net result of this activity is a contact schedule resident on the MOCC disk. This schedule is updated once per week.

(b) There are two Support Computer Program Systems (SCPS)

- o Within the MOCC using MOCC computers
- o External to the MOCC using standard NASA/GSFC SCPS support

As much SCPS activity as possible will be done within the MOCC, but where duplication of extensive already existing capabilities would result the already existing facility will be used.

(c) Housekeeping functions for the EOS spacecraft will be entered via the Mission Planning Console.

(d) The contact messages for each ground contact are prepared by merging the various discrete planning results. There contact messages are then placed on the Mission Operations disk.

The last step in the planning process consists of a careful review of each contact message by the appropriate MOCC personnel. This review process is accompanied by an editing capability via the Project Operations Controllers (POC) and the ground controller. This editing capability is particularly significant, since it will permit last minute changes in the contact message without requiring a complete SCPS recycle.

Mission Execution

The execution phase of mission operations is built around the real time contacts with the EOS, including prepass and postpass configuration and checkout activities. These real time operations are centered around two areas:

(a) The Project Operations Controller (POC) console. The POC is the individual charged with complete responsibility for the safe and effective operation of the EOS during each pass. During the pass he has the responsibility and authority to make all decisions related to this effort. This console is the focal point of the real time operation, and the design emphasis on the console is an effective and complete data and operational display.

(b) The Ground Controller (GC) console. The GC is the individual who operates the MOCC during the real time contact. He has the responsible to implement the contact message, and to respond to all POC direction for action, consistent with the current capabilities of the MOCC.

The POC is also assisted by a group of subsystem specialists who monitor S/C performance during each pass.

At the start of the real time operations the ground controller will, at the POC's direction, cause execution of the appropriate contact message. (a severe S/C problem might cause the POC to abort the message) In the meantime, the POC and his support people monitor the health of the spacecraft.

In terms of data flow, the raw incoming telemetry is fed through the PCM equipment, and then the serial data stream is stored in the computer memory; the peripheral control drives the console displays, printers, and strip chart recorders.

The console displays are centered around interactive CRT's, with á snapshot printer, event printer, and strip chart recorder as backup. Via the interactive CRT each analyst can call up the data most pertinent to the current situation. It will also be possible to easily design a new CRT page and input this new page (via the GC) onto the MOCC system disk. This feature is of special importance when handling a spacecraft problem.

A data compression processor is shown in the MOCC software repetoire. The purpose of this compression is simply to reduce the number of magnetic tapes which must be archived with S/C housekeeping data. In addition to compressing the data it is also planned to store data from a number of contacts on the data and history tape. This approach is being taken for the following reason:

- o Past experience on numerous programs has shown that the vast majority of housekeeping data is never used once the real time pass is completed.
- o Tape usage and storage is an expense that can be easily reduced.

The history portion of the tape is simply a copy of the information contained on the events printer, which contains a record of every significant event during the pass.

Data Analysis

Based on our OAO operations experience, the study and analysis activities conducted during the back orbit periods were structured into three distinct areas:

(a) Analysis of spacecraft anomalies (closeout of formal anomaly reports)

(b) Characterization and quantitization of spacecraft performance (like pointing accuracy studies)

(c) Preparation of improved operating procedures

The first two areas require playback and analysis of spacecraft data. Our approach for analysis software is to place the emphasis on general data handling capabilities such as stripping our selected parameters, data tabulation, plotting routines for both strip charts and X-Y plotters, and the provision of entry points for analyst supplied computational routines. We feel strongly that this approach will yield more effective utilization of software dollars than developing a large series of very specific routines .

There is one obvious exception to this approach. Where mission planning demands a prior analysis of spacecraft data these analyses will be performed by special computer programs. A good example is the attitude determination required prior to orbit adjustment.

11.3 MOCC Hardware

11.3.1 Grouped mini-computer concept

The grouped mini-computer concept utilizes many small relatively inexpensive mini-computers to share the overall processing requirement for the MOCC as opposed to one large central computer burdened with the task of all processing. Reference Figures: 11-3,11-4, and 11-5.

The physical location of the mini-computers is in each console and is dedicated to a specific MOCC function. In addition there is also a mini computer dedicated to control of peripherals in a common peripheral pool.

Because of the individual modular console approach used in the MOCC there is no direct data communications between individual consoles (mini-computers). The media by which the mini-computers communicate is the central shared memory. This shared memory provides all mini-computers in the OCC a common area for both data retrieval and communication.

All the mini-computers used in the MOCC are identical. This commonality is cost effective in terms of procurement and maintainability, and operation.

Central Shared Memory Concept

The central focal point in the grouped mini-computer configuration is the shared memory system. The major components in the shared memory system are:

- o Memory unit
- o Shared memory bus controller (SMBC)
- o Shared memory BUS
- o Shared memory bus interface (SMBI)

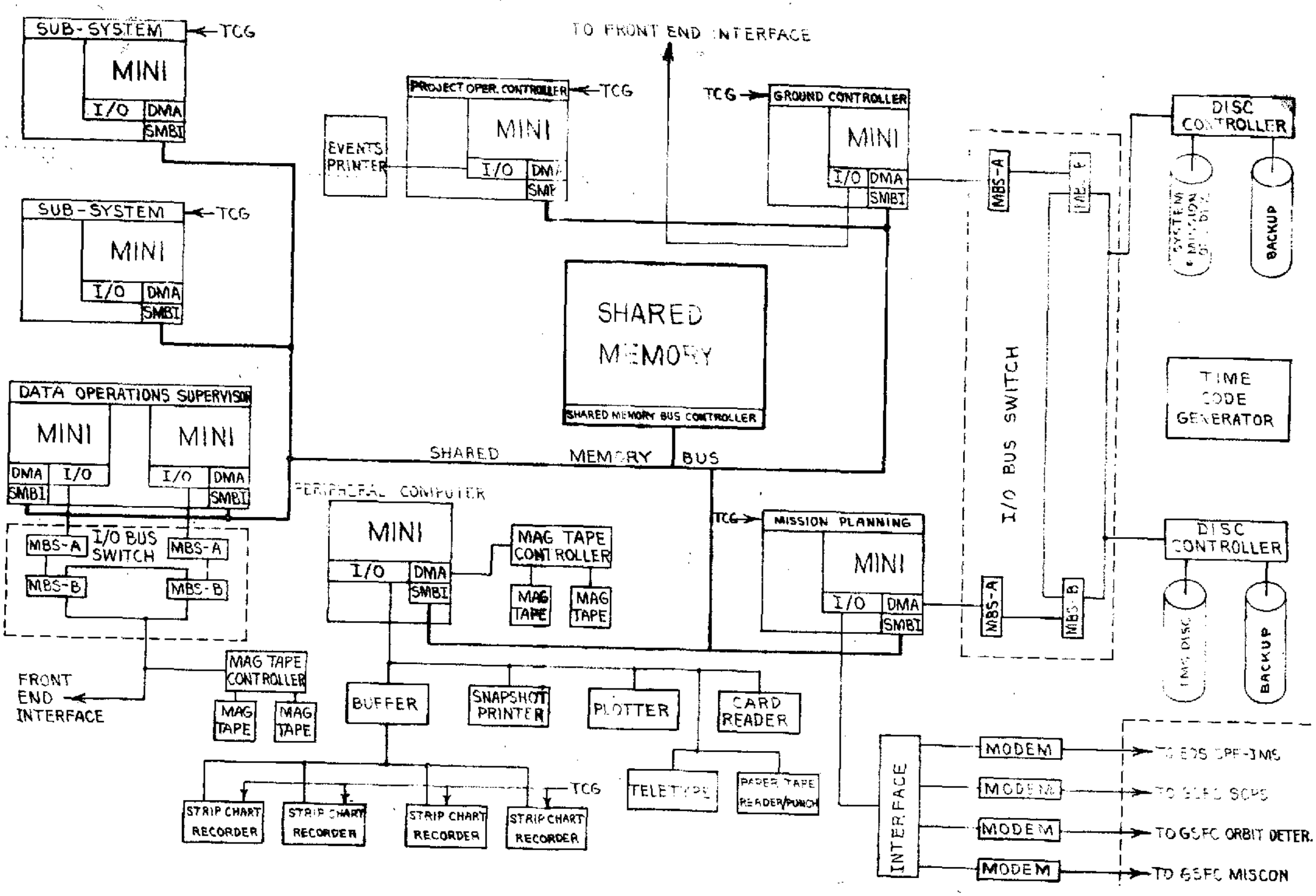


Fig. 11-3 EOS - OCC System Diagram Grouped Mini

The memory unit itself is a standard memory block expandable in block increments.

The shared memory bus controller is the interface between the memory blocks and the shared memory bus. It provides the control to access the memory block(s) as well as provide a priority control scheme to honor memory requests on a priority basis. Parity checking of both address and data is also provided by the controller. The shared memory bus is the interconnecting point for all users of the shared memory.

The shared memory bus interface (SMBI) is the interface between the shared memory bus and the mini-computer. One SMBI is required for every mini-computer connected to the shared memory bus. It is connected to the computers direct memory access channel (DMA) so as to provide the fastest possible means to transfer data to and from the shared memory. As a result the shared memory bus is readily available and eliminates a back log of memory requests from other users.

Internal to the SMBI is a programmable read-only-memory (PROM) which can limit the access capability (write mode only) to various, programmable areas of the shared memory. Each mini-computer tied to the shared memory is programmed (via the PROM) to only write in certain designated blocks of the shared memory while still retaining the capability to read any portion of the shared memory. This prevents unauthorized or accidental changes to dedicated portions of memory.

OCC Data Flow (Figure 11-4)

The downlink housekeeping data enters the OCC from either of two sources. The first source is via the NTTF as GSFC which enters and S-Band antenna into a diplexer, then S-Band receiver and demodulator. AT this point the raw PCM data is recorded on analog tape recorders for future study and backup. The demodulated PCM then enters a bit synchronizer followed by frame synchronization. The data then enters an interface unit to interface with the front end processor (FEP).

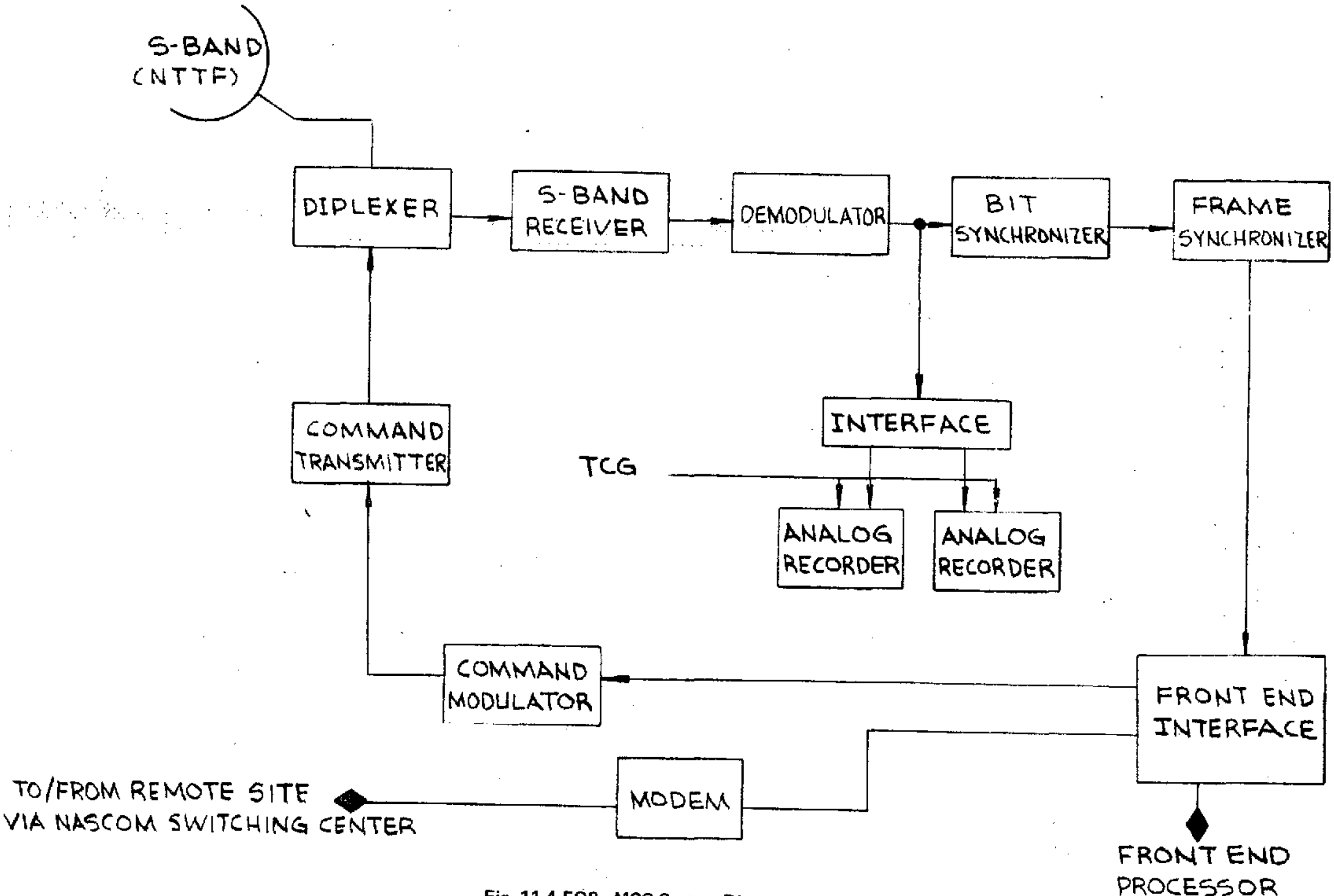


Fig. 11-4 EOS - MCC System Diagram Front End

The second source of down link data is via a remote site input in which case it enters the OCC via a modem and into the FEP interface. All data entering or leaving the OCC passes through the DOS console where it is monitored for quality, etc. and if necessary repatched or rerouted as required. This data then enters the front end processor located in the DOS console via a switched I/O bus. This switched I/O bus is necessary because the FEP has a 100% backup capability with an identical mini-computer, which ensures that a failure of the on-line FEP will not cause a loss of contact with the spacecraft. Switchover may be either automatic under program control or manual.

The PCM data now in the FEP is processed by the FEP and then sent to the shared memory via the shared memory bus for use by the command and display consoles. The processing by the FEP will result in an output of a compressed data/history tape (digital). These tape units are also connected to the switched I/O bus to provide availability to either FEP.

Once the data is in the shared memory it is available to any or all of the consoles. The individual consoles take only that data they wish to further process and/or display on their CRT as determined by their individual software programs. All consoles have available to them a peripheral pool consisting of the following:

- Digital magnetic tapes
- Card reader
- Snapshot printer
- Events printer
- Strip chart recorders
- Plotter

All the peripherals are controlled by a peripheral controller identical to the other mini-computers in the system. The peripheral controller will also have the responsibility of driving the strip chart recorders with selected PCM data items and honor requests for snapshot prints and plots.

The Ground Controllers Console and Mission Planning Console will each have a dedicated disc storage unit and backup. This is necessary due to the frequency of data access and quantity of data to be stored. Because these discs are dedicated to a console, they are placed on a switched I/O bus so in the event of a failure of its console, the other consoles may have access to the information on the disc and at lease assume the functions of the failed console in some satisfactory but degraded mode of operation. Although the real time interface between the mission planning console and the EOS CPF-IMS and GSFC facilities is not on the switched I/O bus, loss of real time contact with these facilities will not greatly hinder operation of the current spacecraft contact.

The uplink data flow originates in the form of commands, either stored on disc or realtime from the ground controller's console. All commands must first be approved by the Project Operation Controller prior to being sent to the spacecraft via the FEP. This safety factor is accomplished by allowing only the computer in the Ground Controllers Console to have write access to a certain area of shared memory into which the command messages are placed for transmission. This write access limitation is performed by the PROM in the SMBI of the Ground Controllers Console.

The commands are then sent to the front end interface unit. The path of the command data is now either to the command modulator, command transmitter, diplexer, S-Band antenna, in the case of a contact over GSFC or to a modem to the remote site via the NASCOM switching center.

OCC Console Description

Each console in the OCC with the exception of the DOS console is a modular design with as much commonality as is feasible. Each console contains the following:

- Mini-computer with local memory and I/O
- Shared memory bus interface
- Interactive alpha numeric CRT and keyboard
- CRT hard copy printer
- Digital cassette system
- Intercom unit
- Command control and displays

The mini-computer with its local memory and I/O is the heart of every console. It performs the processing required unique to the console and interfaces with every other console via the shared memory. The computer also configures the command control and display panel(s). Switches and indicators are not dedicated to a specific function but take on any function determined by the software program. This flexibility allows each console to function as any other console similarly configured by simply loading in the correct software program(s).

The shared memory bus interface allows each console to communicate with any other console via the shared memory. It contains the logic needed to specify what individual blocks of memory a computer is permitted to write into. This hardware protection affords the entire system security in knowing any one computer cannot clobber the system in the event of a processor malfunction.

The digital cassette system provides a means of bootstrapping a program into the computer. They will be needed for each cold start of a console and, additionally, may be used by the maintenance personnel to enter diagnostic/operational readiness programs into the computer when servicing the console, either on line or off line. It may also be used to obtain selected data items at intervals for use in trend analysis.

The interactive alpha numeric CRT display and keyboard is the major man-machine interface media. It allows display, in page form, of any data required by the function of its console. It also allows for manual entry of data or commands into the system, via the keyboard. The flexibility of using this unit via software, provides almost unlimited control over the function of a console in relation to the overall system.

The CRT hard copy printer provides the operator a means of obtaining a hard copy of the data currently being displayed on the CRT.

The intercom unit in each console provides each operator a means of voice communication with any other operator or OCC personnel.

The command control and display panel will contain the following components:

- Event lite displays
- Digital readout analog displays
- CRT page selector switch
- Command switches

The panel will be completely computer controlled and therefore, no switch or display, with the exception of the CRT page selector, will be dedicated a specific function. The function of each display and switch will be defined by the software program of the individual console. In order to provide a visual indication of the function of each display and switch an overlay will be fitted to each command control and display panel. This overlay panel in conjunction with the software program will define the display and command capabilities of the individual console. Some of the possible uses of the components of the command control and display panel are:

Event displays - Display of critical downlink event data from the spacecraft a means of alerting the operator to perform some task, etc.

Analog display - Display of critical downlink analog data from the spacecraft

CRT page select- Select a particular page of data to be displayed on the CRT.

Command Switches- Defined use virtually unlimited. Selection of snapshot programs. Selection of catalogued command sequences to be sent to the spacecraft. Selection of specific software routines to be run.

The computer controlled command control and display panel is designed to be extremely flexible with regard to configuration and functi on.

The Data Operations Supervisors console (DOS) is the central monitor and distribution point for the OCC's data lines. The console is different with respect to all other OCC consoles, due to its unique function. The console contains the analog and digital amplifiers required for signal conditioning, oscilloscopes, and frequency meter etc., required for signal monitoring. The console also contains patchboards for signal routing. In addition, both front end processors (on-line and backup) are housed in the DOS console

11.3.2 Central Midi-Computer Concept Fig/ 11-5

The central midi-computer concept utilizes two medium scale computers (CPU A& B) with a common memory operating in a multi-processing environment. Each processor has two dedicated disc units and two magnetic tape units. The individual consoles are preliminary driven by CPU-A whereas the external interfaces and peripheral pool units are primarily driven by CPU-B.

This multi-processor configuration has a backup capability in the event of failure of one of the CPU's. Although some less essential processing may have to be eliminated in the backup mode, control and monitoring of the spacecraft is still maintained.

The backup capabilities of the CPU's must further be extended to the rest of the system. If the system is put into an emergency mode of operation, the units primarily driven hy the failed computer must have the capability to be switched to the operable computer.

The content of the peripheral pool is the same as the grouped mini-configuration except for the teletype. Each unit in the peripheral pool is capable of being switched to either computer.

The external configuration of the consoles is also the same as the grouped mini-configurations, however, the internal configuration differs. The elimination of the computer internal to each console, requires additional logic to be incorporated into the consoles for purpose of interfacing the alpha-numeric CRT and command control and display panel with the central processor.

Data flow through the front end equipment is the same as the mini-configuration. Only processing and display of the data differs.

Summary:

The mini-computer configuration is the most flexible and tolerant to changes and growth. Although both systems incorporate backup capability the mini configuration is inherently redundant. If one console goes down, a less essential console can be re-programmed quickly to take over the faulty consoles function. The mini approach will more easily support on-line diagnostics because it does not require

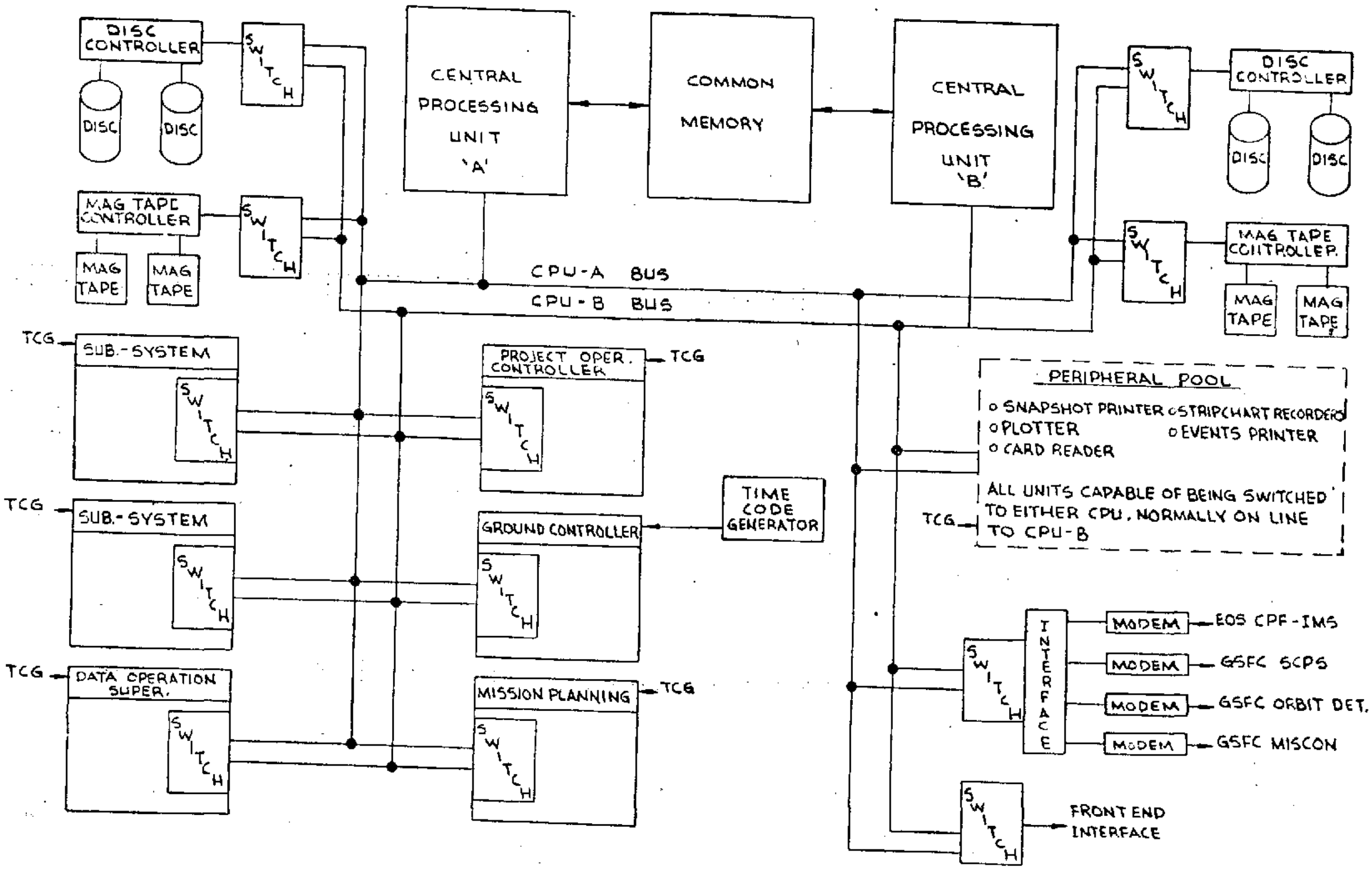


Fig. 11-5 EOS - MCC System Diagram Central Midi

a central computer interface. Both systems have console modularity which is cost effective in the following areas:

- o Procurement in quantity
- o Reduced spares inventory
- o Reduced engineering drawing effort
- o Reduced manufacturing costs
- o Console diagnostics the same

The mini-computer configuration will result in reduced maintenance costs. This will also lower training costs and enable faster diagnosis thus reducing downtime.

The central midi-computer configuration will require less software effort than the mini-computer configuration. Although the same MOCC processing requirements exist in either configuration additional software must be developed for inter-computer communications in the mini-computer configuration.

11.4 MOCC MANPOWER

The manpower requirements for the MOCC effort are broken down into two prime areas.

(1) Pre-launch MOCC development phase (Figure 11-6)

(2) On-going operations following launch. These are discussed in the following paragraphs. (Figure 11-7)

Pre-Launch Phase

Starting with contrast go-ahead for the EOS spacecraft there must be a parallel effort for the MOCC area. This pre-launch phase for the MOCC area is concerned simply with getting ready to fly the EOS, and the effort is broken down into four distinct areas as follows:

(1) MOCC Design and Development - this activity is concerned with defining the MOCC hardware configuration, negotiating hardware interfaces, performing detail design, and actual development and proof testing of the MOCC. MOCC hardware documentation is included.

(2) SOFTWARE DESIGN AND DEVELOPMENT - this activity is concerned with defining and developing all of the software which will run within the MOCC, including documentation, test plans, and proof testing. A mission simulation effort is also included, although part of this, if not all, will run external to the MOCC.

(3) MISSION PLANNING - this activity is concerned with defining the exact procedures and facilities (within the bounds of 1 and 2 above) to be used in the performance of the EOS mission. The major activities are:

- Mission Plan Development - launch survival initial and on-going operations
- Command and Telemetry Management - receiving and steering the EOS command and telemetry complement to assure that the required operational commands and information is available.
- MOCC Display Design - CRT's, printouts, strip charts, status lights, meters, etc.
- Command Pool Definition
- Status Data Limit definition
- SCPS specifications
- Formulation of mission constraints and rules

G. ALBRIGHT

MOCC
MISSION OPERATIONS TIME LINE
PRE-LAUNCH

(p1/2)

Months 1–12 (months after ATP)

	1	2	3	4	5	6	7	8	9	10	11	12
MOCC DESIGN & DEVELOPMENT												
MOCC DETAIL DESIGN	1	1	1	1	1	1	1	1	2	2	2	2
MOCC DEVELOPMENT												
INTERFACE CONTROL							1	1	1	1	1	1
FACILITY DESIGN												
PROOF TEST												
PROCUREMENT												
DOCUMENTATION										1	1	1
SUB TOTAL	1	1	1	1	1	1	2	2	3	4	4	4
SOFTWARE DESIGN & DEVELOPMENT												
PERFORMANCE & DESIGN REQUIREMENTS	1	1	1	2	2	2	2	2	3	3	3	3
IMPLEMENTATION CONCEPT & TEST PLAN							1	1	1	2	2	2
INTERFACE & DATA REQUIREMENTS												
DETAILED DESIGN SPECIFICATION										1	1	1
CODING												
SYSTEM DEVELOPMENT TESTING												
PROOF TEST & ACCEPTANCE												
SUBTOTAL	1	1	1	2	2	2	3	3	4	6	6	6

Months 13–24

	13	14	15	16	17	18	19	20	21	22	23	24
MOCC DESIGN & DEVELOPMENT												
MOCC DETAIL DESIGN	2	2	4	4	4	4	4	4	3	3	3	3
MOCC DEVELOPMENT	2	2	2	4	4	4	6	6	6	6	6	6
INTERFACE CONTROL											1	
FACILITY DESIGN	1	1	1	1	1	1	1	1	1	1	1	1
PROOF TEST										2	2	3
PROCUREMENT	1	1	1	1	1	1	1	1	1	1	1	1
DOCUMENTATION	2	2	2	2	2	2	2	2	2	2	2	2
SUB TOTAL	8	8	10	12	12	12	14	14	13	15	16	16
SOFTWARE DESIGN & DEVELOPMENT												
PERFORMANCE & DESIGN REQUIREMENTS	2	1										
IMPLEMENTATION CONCEPT & TEST PLAN	3	3	3	4	4	5	5	6	6	6	4	4
INTERFACE & DATA REQUIREMENTS	1	1	1	1	1	1	1	1	1	1		
DETAILED DESIGN SPECIFICATION	2	2	2	3	3	4	4	4	4	4	4	4
CODING	2	2	2	2	2	2	3	3	3	3	4	4
SYSTEM DEVELOPMENT TESTING	2	2	2	2	2	2	2	2	4	4	6	6
PROOF TEST & ACCEPTANCE												
SUBTOTAL	13	11	10	12	12	14	15	16	18	18	18	18

Months 25–36 and totals

	25	26	27	28	29	30	31	32	33	34	35	36	TOTALS
MOCC DESIGN & DEVELOPMENT													
MOCC DETAIL DESIGN	1	1	1										59
MOCC DEVELOPMENT	6	6	6	6	6	6	5	5	5	5	5	5	120
INTERFACE CONTROL	1		1		1		1		1				12
FACILITY DESIGN	1	1	1	1	1	1							18
PROOF TEST	4	4	4	4	3	3	2	2	2	2	2	2	41
PROCUREMENT	1	1	1	1	1	1	1	1	1	1	1	1	24
DOCUMENTATION	3	3	3	2	2	2	2	2	2	1	1	1	51
SUB TOTAL	17	16	17	14	14	13	11	10	11	10	10	10	325 MAN MONTHS
SOFTWARE DESIGN & DEVELOPMENT													
PERFORMANCE & DESIGN REQUIREMENTS													28
IMPLEMENTATION CONCEPT & TEST PLAN	3	1	1										67
INTERFACE & DATA REQUIREMENTS													10
DETAILED DESIGN SPECIFICATION	2	2	2										49
CODING	4	4	4	4	4	4	4	4	4	4	4	4	80
SYSTEM DEVELOPMENT TESTING	8	8	6	6	6	4							74
PROOF TEST & ACCEPTANCE				2	4	4	4	4	6	6	6	6	42
SUBTOTAL	17	15	13	12	14	12	8	8	10	10	10	10	350 MAN MONTHS

MONTHS AFTER ATP

Fig. 11-6

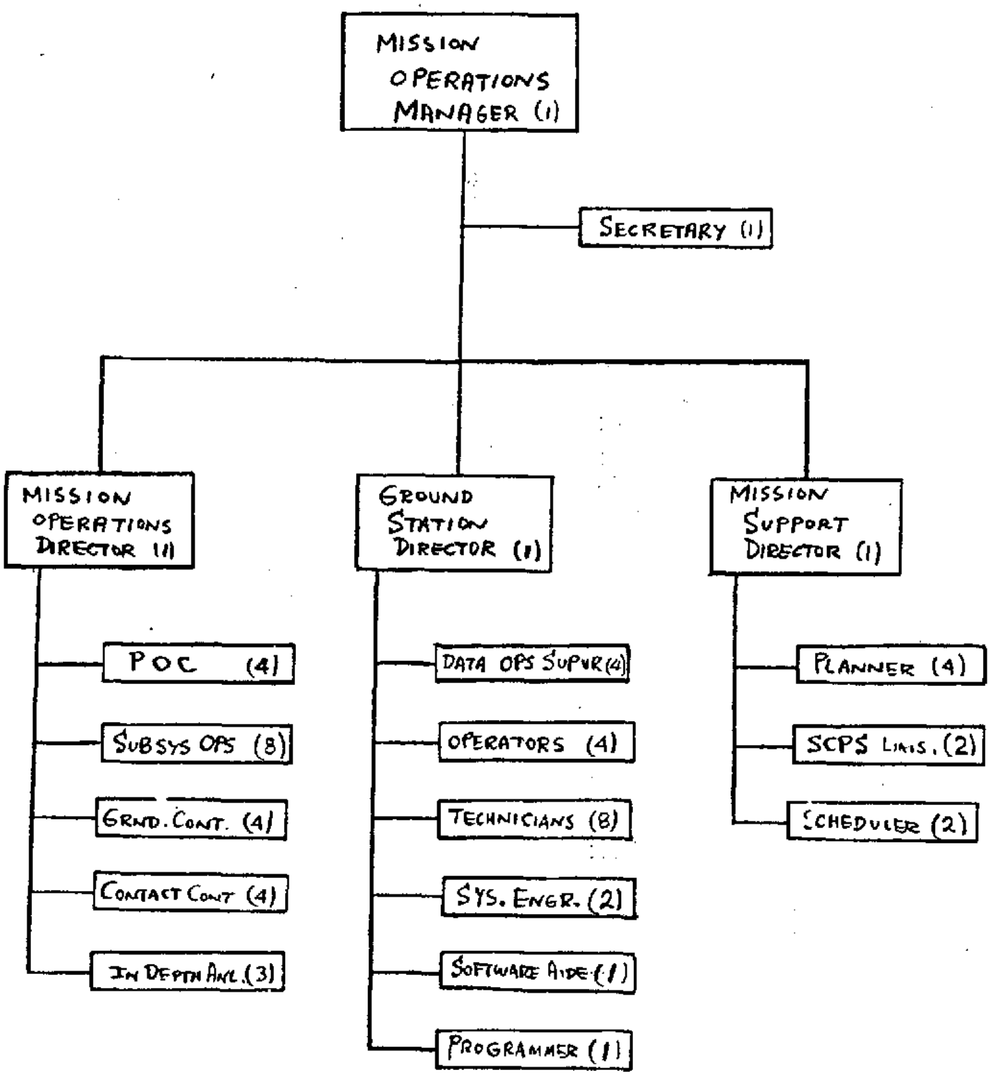
MOCC
Mission Operations Time Line
Pre-Launch

G. Albright

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	TOTALS
MISSION PLANNING																																					
Mission Plan Development													1	1	1	1	1	1	2	2	2	2	2	2	3	3	3	3	3	3	3	3	2	2	2	2	50
Command & Telemetry Management	1	1	1	1	1	1	1	1	1	1	1	1													1	1	1	1	1	1							18
Display Design																											1	1	1	1	1	1	1	1			8
SCPS Liaison	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	3	3	3	3	3	3	3	3	3	2	2	2	2	2	1	1	1	1	65
Software Specification	1	1	1	2	2	2	3	3	3	3	3	3	2	2	1	1	1																				34
Sub Total	3	3	3	4	4	4	5	5	5	5	5	5	5	5	4	4	4	3	5	5	5	5	5	5	7	7	8	7	7	7	6	6	4	4	3	3	175 MAN-MONTHS
MISSION PREPARATION																																					
Simulation Specification							1	1	1	1	1	1	2	2	2	2	2	2	2	2	3	3	3	3	3	3	3	3	3	3	2	2	2	1	1	1	61
Simulation Participation																													9	10	20	20	30	30	30	30	179
Design Reference Manuals													1	1	1	2	2	2	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	2	2	2	60
Sub Total							1	1	1	1	1	1	3	3	3	4	4	4	5	5	6	6	6	6	6	6	6	6	15	16	25	25	35	33	33	33	300

Fig. 11-6 (continued)

MOCC
MANPOWER REQUIREMENTS
ON-GOING OPERATIONS



ADDITION FOR SECOND S/C

4 POC
1 IDA
4 CONTACT CONT.

4 OPERATORS

4 PLANNERS

Fig. 11-7

(4) MISSION PREPARATION - this activity is concerned with ensuring that the three areas described above are coordinated into a smoothly functioning system by the time of launch. A simulations effort is control to this effort; design reference manuals similar to those prepared on OAO are also included.

The manpower spread for this pre-launch phase is given in table 2.

ON-GOING OPERATIONS

The MOCC organization for the on-going flight operations is broken down into three areas:

(1) MISSION OPERATIONS - this group is concerned with the real time support of the EOS, and with the detailed operational analyses and planning following launch.

(2) GROUND STATION - this group is concerned with the operation and maintenance of the MOCC hardware

(3) MISSION SUPPORT - this group is concerned primarily with the effective planning of the EOS operations. Interfacing with the CPF-IMS is of centeral importance in this area. This area also interfaces with NASA/GSFC MISCON, orbit determination, and SCPS group.

The manpower organization is given in figure 4. Fifty six people are required to support one EOS on a four shift 24 hour per day basis. An additional 17 people are required to support an additional spacecraft in the same control center.

SYSTEM TRADE
STUDY NO. 12

GRUMMAN AEROSPACE CORPORATION

TRADE STUDY REPORT

TITLE	TRADE STUDY REPORT NO. 12
Coupled Vs. Uncoupled Pneumatics	WBS NUMBER 1.2.1.2.6

See Report No. 3, Section 6.12

PREPARED BY	GROUP NUMBER & NAME	DATE	CHANGE LETTER
			REVISION DATE
APPROVED BY			PAGE 12-1

GAC 3711
2-72

GRUMMAN AEROSPACE CORPORATION

TRADE STUDY REPORT

TITLE	TRADE STUDY REPORT NO.
Wide Band Data Format	13
	WBS NUMBER

See Report No. 3, Section 6.13

PREPARED BY	GROUP NUMBER & NAME	DATE	CHANGE LETTER
			REVISION DATE
APPROVED BY			PAGE 13-1

GAC 3711
3-72

SYSTEM TRADE
STUDY NO. 14

TRADE STUDY REPORT

TITLE	TRADE STUDY REPORT NO.
MODULARITY LEVEL	14
	WBS NUMBER

See Report No. 3, Section 6.14

PREPARED BY	GROUP NUMBER & NAME	DATE	CHANGE LETTER
			REVISION DATE
APPROVED BY			PAGE 14-1

SYSTEM TRADE
STUDY NO. 15

15. Follow-on Mission Economic Study

Purpose:

The purpose of this study is to determine the economic benefits in utilizing multi-mission spacecraft to capture varying numbers of earth observation missions, and to evaluate the cost impact of extending the GAC baseline design to capture the EOS missions B through E plus SEASAT A, SEOS, and SMM.

Conclusions:

- Conducting all missions with single-mission spacecraft is the most expensive approach.
- Program cost savings increase with increased mission capture capability of multiple-mission spacecraft.
- Greatest program cost savings compared to single-mission spacecraft approach were achieved through addition of performance capability to the Grumman basic spacecraft to capture EOS missions B through E plus SEASAT A, SMM, SEOS.

Table 15-1 presents the projected percentages of net cost savings for all missions considered. The upper three groups represent increasing mission-capture capability, with the top group representing single-mission spacecraft used as cost reference in computing the percentages shown. The fourth group represents the approach involving extensions of the GAC baseline spacecraft to capture each mission, with percentages referenced to the single-mission spacecraft approach. The columns indicate cost categories.

Table 15-2 presents cost savings for individual missions.

Both tables are basically cost comparisons of multiple-mission spacecraft (subsystem modular designs) against the corresponding single-mission spacecraft (subsystem modular design) for the same missions.

In the multiple-mission spacecraft case the subsystem modules are designed to meet the most stringent performance requirements in the mission set. Thus there are instances when the subsystems will operate below their design performance level. In the single-mission spacecraft case no such instances occur because the subsystem modules are matched to the particular mission requirements.

Extensions of the GAC baseline design were also evaluated against the corresponding single-mission spacecraft. The GAC baseline extension approach was not to build in subsystem performance to meet the most stringent mission in a set, but to capture additional missions by adding mission-peculiar subsystem performance capability as required. Both tables indicate that the GAC baseline extension approach compares favorably with the multiple-mission modularity approach. In table 15-1 the GAC baseline approach yields a 31% saving in DDT&E, a 22% saving in DDT&E and production, and 17% saving in DDT&E, production and operations, based on the projected costs of all mission considered. A 19% saving in DDT&E, production and operations was computed, when the projected cash flows were discounted at 6%. The slight difference between the undiscounted (17%) and discounted (19%) savings were caused by the effect of time on the cash flows.

Table 15-2 indicates an initial net total program cost increase for EOS missions A and B, for the multiple-mission modular design approach. These additional costs, however, are recouped when additional missions are flown. The GAC baseline extension approach indicates a net saving for all missions considered.

Table 15-3 indicates the modification, and their cost percentage increments to the GAC baseline Spacecraft platform in extending the baseline capability in capturing additional missions. The difference between these percentages and those in Table 15-2 are that here the instrument costs are excluded, while in Table 15-2 they were included.

Discussion:

General Description of Study Approach:

The study is essentially a cost comparison of the following ways of accomplishing EOS Missions A through E and also SEOS, SMM and SEASAT A.

- o All flights by single-mission spacecraft, each tailored to the requirements of its mission.
- o Various spacecraft mixes comprising a multi-mission spacecraft capturing Mission A plus one or more of the other missions and single-mission spacecraft covering the remainder of the missions. In each case the multi-mission spacecraft would have subsystems meeting the most stringent mission in its set.

- Extension of the GAC baseline spacecraft by adding mission-peculiar capabilities as needed for each mission.

The economic impact of the multi-mission spacecraft and GAC basic extension concept manifested itself in initial costs and future savings in three major cost categories DDT&E, Production and Operations. NASA in-house management costs were excluded, as well as the DMS costs and certain Facilities costs. It was assumed that these costs were insensitive to the type of spacecraft designs studied. Cost estimates were developed for launch vehicle and launch operations, mission-peculiar instruments, flight operations and services, and spacecraft GSE, logistic support and facilities.

The cost estimating methodology employed was generally parametric, although some key items were estimated by a detailed engineering accounting. The parametric approach to spacecraft cost estimation was consistent with the depth of design within the scope of this study.

The following assumptions were basic to the study:

- Missions will be flown with subsystem-modular spacecraft of either single-mission or multi-mission type.
- All spacecraft are retrievable by the Shuttle.
- Shuttle available from WTR in 1983.
- All spacecraft are flight serviceable.
- Operations costs start with the first launch.
- Design-life of spacecraft is 2 years except D (5 years).
- Resupply flights are made every two years after the Shuttle becomes available.
- Spares are obtained from the prototype qual model.

Subdivision of Study into Tasks

The study was divided into the following three functional tasks to facilitate delegation of the work:

Task 1 - Determination of cost - related spacecraft subsystem characteristics and launch vehicle requirements.

Task 2 - Cost estimation and summarization.

Task 3 - Economic analysis.

A breakdown of these tasks is given in the study flow diagram (Figure 15-1). Referring to Figure 15-1, a description of each task is as follows.

Task 1

The initial drive in this task was to establish mission requirements which define the spacecraft subsystems, (item 1.1), and to select the various mixes of single-mission and multiple-mission spacecraft to be studied (item 1.2). Both of these items then input to the subsystem design activity (item 1.3). Subsystems involved in the portion of the study were ACS, EPS, C/DH, Orbit Adjust and Structure.

Subsystem properties (weight, volume) derived from the subsystem design activity were applied to a configuration analysis (1.4) to a determination of the structural weight of the spacecraft (1.5) and to the specification of the launch vehicle (1.6).

The output of this task (1.7) consisted of the spacecraft and launch vehicle data needed for program cost estimation in the following task.

Task 2

The objective of this task was to generate program costs (including spacecraft, GSE, launch vehicle, etc.) associated with single-mission and multi-mission spacecraft considered in the study. Each program cost estimate is the sum of three major segments: DDT&E, Production, and Operations.

Program scenarios were developed for each mission in the study (2.1) to aid in estimating operations costs by fixing start and end dates of DDT&E, Production and Operations, launch dates (initial as well as re-supply) and retrieval dates. This information also enabled determination of spacecraft production quantities.

Recurring operations costs (2.2) were estimated in the following categories:

- Launch vehicle and launch operations
- Flight operations and services for the spacecraft platform (excluding Mission-peculiar equipment data management)
- Spacecraft logistic support.

Non-recurring facility and GSE/STE costs were estimated for each mission (2.3).

Mission peculiar instrument costs (non-recurring and unit recurring) were compiled from vendor data and/or estimated by analogy.

Cost estimating (2.5) was performed by a hybrid, parametric/accounting estimate approach. Table 15-4, based on the gross level Work Breakdown Structure, indicates which items were costed by each method and the items omitted from the overall cost estimate.

The parametric cost model was the computerized SAMSO model for unmanned spacecraft detailed in SAMSO TR. No. 73-247 and dated July 1973. The model generates life-cycle cost data and provides the traceability and consistency of results necessary for the performance of the economic analysis in Task 3. Inputs to the model are spacecraft physical and performance parameters, as well as the estimated cost data detailed in Table 15-5. The model consists of a set of spacecraft subsystem cost estimation relationships (CER's) which are statistical regressions from a historical spacecraft cost data bank. The model incorporates several "vehicle level" cost estimating factors for estimating such costs as System Engineering, and Management. The model does not estimate all cost elements in the total life cycle or program cost matrix. These costs, notably the recurring operational costs, were estimated "off line" and then inputted in the model. The output of the model is in the general categories of DDT&E, Production, and Operations. DDT&E, and Production costs are generated at the spacecraft subsystem level, which was detailed enough to allow performance of the economic analysis in Task 3.

Task 3

The purpose of this task was to perform the economic analysis of cost data generated in the previous task.

The cost estimates from the previous task were modified to reflect learning acquired in earlier development of closely similar spacecraft (3.1).

A computer program called Total Program Cost Distribution, TPCOD2, was used to generate annual funding distribution both undiscounted and discounted to 1974 dollars (3.2). Annual funding distributions were made for all the single-mission spacecraft and multiple-mission spacecraft in the three major cost categories of DDT&E, Production, and Operations. The funding distributions in these categories were made in accordance with pre-selected beta-distribution functions and the start and end dates of the given expenditures.

Item 3.3 refers to final comparison and analysis of the cost information.

Discussion of Task 1-Work:

Objective:

The purpose of this task is to define spacecraft subsystem characteristics needed for determination of spacecraft costs and for establishment of launch vehicle properties.

Definition of Spacecraft Subsystem Requirements:

The EOS mission requirements are summarized in Figure 15-2. These are presented as profiles to emphasize the cost drivers. For example, it is apparent from the profiles that the instrument power requirements for Mission EOS-D call for the maximum output power subsystem in the entire mission

These requirements were translated into spacecraft subsystem designs of sufficient depth to establish weights, solar array area, etc., as needed for estimating spacecraft costs.

Selection of Spacecraft for Study

Eight missions were considered in the study, namely EOS A, B, C, D (SEASAT B), E (Tiros O), F (SEOS), G (SEASAT A), and H (SMM). Spacecraft considered were:

- Eight single-mission spacecraft, one for each mission.
- Eight Grumman basic spacecraft, each with mission-peculiar additions to GAC "standard" subsystems as needed to capture each mission.
- A multi-mission spacecraft with "high-performance" subsystems capturing missions A to C, accompanied by single mission spacecraft for missions D to H.
- A multi-mission spacecraft with "high-performance" subsystems capturing missions A to E, accompanied by single-mission spacecraft for missions F to H.

For the cases involving a mix of multi-mission and single-mission spacecraft, the fundamental objective was to establish the lowest total program cost for all 8 missions. This will depend upon the cost of the multi-mission vehicle and the cost of its accompanying single-mission vehicles. As the multi-mission spacecraft captures more and more missions it acquires weight, complexity and, in some cases, increased launch vehicle costs. Simultaneously, with increased capture capability of the multi-mission spacecraft, the number (hence cost) of the accompanying single-mission spacecraft decreases. The minimum cost situation is represented by some combination (multi-mission vehicle and its accompanying single-mission spacecraft) out of many possible combinations. Two such combinations were selected for this initial phase of the study, one having a multi-mission spacecraft with moderate capture capability (A to C) and one with fairly extensive capture capability (A to E). These selections were based on the original mission model consisting of EOS A to E. It was assumed that the most economical spacecraft combination would be one involving the smallest number of single-mission spacecraft. This is a reasonable assumption unless the development cost or launch vehicle cost of a highly capable multi-mission vehicle were to offset the cost savings resulting from few single-mission vehicles.

Based on the size of the current mission model (8 missions), there are now 127 possible combinations of single and multi-mission spacecraft which could capture the 8 missions, each multi-mission spacecraft accompanied by single-mission spacecraft as needed. Each such mix represents a potential minimum cost program of 8 missions. Since it is impractical to cost all 127 spacecraft designs, the number was greatly reduced by the approach illustrated in Table 15-6.

Table 15-6 considers all possible multi-mission spacecraft for the 8-mission program, 127 in all (Column 1) grouped in accordance with their subsystems capabilities (Column 2). Since all spacecraft in a group contain the same subsystems they are quite similar from a spacecraft cost standpoint. They all differ, however, from an 8-mission total program cost standpoint because each requires a different number of accompanying single-mission spacecraft to complete the total program of 8 missions. The greater the capture capability of the multiple-mission spacecraft in a group, the fewer are the required single-mission spacecraft. The minimum program cost for a group was assumed to be the one with the fewest single-mission spacecraft, with the reservation that there is a greater weight and complexity of the multiple-mission spacecraft and the possibility of an increased launch vehicle lift requirement for some missions. Thus the group member suggested for cost estimate would be the one with fewest accompanying single-mission spacecraft. As a check on the above assumption, some group members with more than the minimum number of dedicated spacecraft should also be selected for cost estimation in the next phase of the study. Suggested selections are marked on Table 15-6.

Progressing down Table 15-6, the cost of the multi-mission spacecraft in each group decreases because the subsystem capabilities decrease, but the minimum number of single-mission spacecraft (hence program cost) increases. At some point in the table the program costs become prohibitive and groups below this point can be elininated.

With the above approach the number of cases to be considered was reduced from 127 to approximately 10.

Results

The results of this task were selections of spacecraft to be studied and determination of their weight and performance factors necessary for the spacecraft costing and launch vehicle determination.

Discussion of Task 2 - Work:

Objective:

The purpose of this task was to generate program cost estimates, missions EOS-A to EOS-E, SEOS, SEASAT-A and SMM for each mix of single mission spacecraft and multiple mission spacecraft considered in this study.

Approach:

The cost estimating function was accomplished by means of the SAMSO Cost Model for Unamanned Satellites, as presented in SAMSO TR No. 73-247, July 1973. Grumman has computerized this model, for use in generating projections of Life Cycle Cost, LCC, for future unmanned spacecraft program concepts.

The core of this model consists of a set of spacecraft subsystem parametric cost estimating relationships, CER's. Parametric estimates of this type maintain the basic premise that the cost of developing or producing a given system or subsystem is related in a quantifiable fashion to its physical or performance characteristics. The costs of a given system or subsystem are related mathematically to a cost generating variable or variables, such as weight, solar array area, and solar array output. The CER's in the SAMSO model are statistical regressions of cost data from 19 Air Force, NASA and COMSAT unmanned spacecraft programs relating cost, the dependent variable, to physical and performance parameters of the spacecraft, the independent variables. The CER's were developed for the direct cost. In addition to the CER's the model incorporates several cost factors which are applied on intermediate cost data at different stages of the estimating process. Some cost items are not estimated by the model; these costs, notably the launch vehicle, recurring operations costs, and instruments, must be estimated "off line" and then inputted to the model, where they are combined with costs generated internally. Figure 15-3 indicates the scope of the model as applied to the Follow-on Mission Economic Study. Table 15-7 is the Cost Model matrix showing the cost categories. Figure 15-4 is the cost model flow chart for a typical cost estimating procedure. The input requirements and output categories are presented in Tables 15-5 and 15-8 respectively.

The specific factors for design inheritance were developed for each spacecraft subsystem based on GAC experience with the OAO and they were the weighted averages for design and test requirements to integrate the specific set of mission instruments and to provide for the selected launch vehicle environments.

A computer routine was provided to compile the DDT&E cost data from Task 2 in a file and to operate on this file by the design inheritance factors. The output of this intermediate operation was then fed in a computer program called the Total Program Cost Distribution, TPCOD2, which was used to generate annual funding distributions both undiscounted and discounted to 1974 dollars. (3.1). Annual funding distributions were made for all the single-mission spacecraft programs and for all the multiple-mission spacecraft programs; they were generated for the three major cost categories of DDT&E, Production and Operations. The funding distributions in these categories were generated in accordance with pre-selected beta-distribution functions, and the start and end dates of the expenditures.

Referring to items 3.2 and 3.3 in the work flow diagram, NASA's additional costs and future savings were determined for each mission mix. The process is illustrated as follows:

Let A, B, C, D, E be the specified missions in the mission model.

Let D_A, P_A, O_A, be the DDT&E, Production and Operations costs for Mission A, utilizing a mission-dedicated spacecraft.

Let D_B, P_B, O_B, be the above category costs for mission B, etc.

Let D_{AB}, P_{AB}, O_{AB} be the DDT&E, Production, and Operations costs for a multiple-mission spacecraft capable of flying missions A and B.

Let D_{ABC}, P_{ABC}, O_{ABC} be the analogous costs for a multiple-mission spacecraft capable of flying missions A, B, and C.

Let Δ D be the additional DDT&E cost which is incurred if additional performance capability is added in the EOS-A spacecraft subsystem modules (EPS, ACS, and C/DH).

Let Δ P and Δ O be analogous incremental costs in the Production and Operations cost categories.

Let SD, SP, SO be the savings realized in DDT&E, Production and Operations, when multiple-mission spacecraft are utilized.

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In order to determine the additional cost penalty for combining missions A, B, and C in a multiple-mission spacecraft, for example, the following expressions were used:

$$D_{ABC} = D_{ABC} - D_A$$

$$P_{ABC} = P_{ABC} - P_A$$

$$O_{ABC} = O_{ABC} - O_A$$

To determine the savings realized when combining missions A, B and C in a multiple mission spacecraft, the following expressions were used:

$$SD_{ABC} = D_A + D_B + D_C - D_{ABC}$$

$$SP_{ABC} = P_A + P_B + P_C - P_{ABC}$$

$$SO_{ABC} = O_A + O_B + O_C - O_{ABC}$$

The above algorithm was performed on the individual mission basis, as well as for the total of all the missions considered in the study.

TABLE 15-1 PROJECTED COST SAVINGS

S/C MISSION CAPABILITY LEVEL	MISSION	% SAVINGS IN DDT&E FOR ALL MISSIONS	% SAVINGS IN DDT&E + PRODUCTION FOR ALL MISSIONS	% SAVINGS IN TOTAL PROG. FOR ALL MISSIONS	% SAVINGS IN TOTAL PROG FOR ALL MISSIONS DISCOUNTED @ 6%
A Only	A				
B Only	B				
C Only	C	0	0	0	0
D Only	D				
E Only	E				
SEASAT A only	SEASAT A				
SEOS only	SEOS				
SMM only	SMM				
A to C	A				
A to C	B				
A to C	C	4%	1%	1%	1%
D only	D				
E only	E				
SEASAT A only	SEASAT A				
SEOS only	SEOS				
SMM only	SMM				
A to E	A				
A to E	B				
A to E	C				
A to E	D	19%	10%	8%	8%
A to E	E				
SEASAT A only	SEASAT A				
SEOS only	SEOS				
SMM only	SMM				
GAC B/L	A				
GAC B/L Extended	B				
	C	31%	22%	17%	19%
	D				
	E				
	SEASAT A				
	SEOS				
	SMM				

TABLE 15-2 - PROJECTED TOTAL PROGRAM COST SAVINGS BY MISSION

S/C Mission Capability Level	EOS Mission	% Savings by Mission
A only	A	0
B only	B	0
C Only	C	0
D Only	D	0
E Only	E	0
SEASAT-A only	SEASAT - A	0
SEOS Only	SEOS	0
SMM only	SMM	0
A to C	A	-16
A to C	B	-4
A to C	C	27
D only	D	0
E only	E	0
SEASAT-A only	SEASAT - A	0
SEOS only	SEOS	0
SMM only	SMM	0
A to E	A	-18
A to E	B	-4
A to E	C	27
A to E	D	21
A to E	E	27
SEASAT-A only	SEASAT - A	0
SEOS only	SEOS	0
SMM only	SMM	0
GAC B/L	A	1
GAC B/L Extended	B	1
GAC B/L "	C	20
GAC B/L "	D	21
GAC B/L "	E	22
GAC B/L "	SEASAT-A	14
GAC B/L "	SEOS	24
GAC B/L "	SMM	39

NOTES:

EOS-A and EOS B missions include 2 S/C Each

EOS-C, D and E missions include 1 S/C Each

SEASAT-A, SEOS, and SMM include 1 S/C Each

Table 15-3 - MODIFICATIONS TO THE BASIC GRUMMAN EOS

SPACECRAFT TO CAPTURE ADDITIONAL MISSIONS

MISSION CAPTURED	SUBSYSTEM CHANGES REQUIRED					IMPACT ON BASIC S/C COST	
	EPS	ACS	COMM & DH	OA	Structure	DDT&E	PROD.
A	NONE	NONE	NONE	NONE	NONE	0	0
B	NONE	NONE	NONE	Add 1 tank.	Increase capability.	4%	2%
C	Add 2 batteries (each 20 amphrs. & solar array area	Heavier wheels and torquers	NONE	Add 2 tanks. Add SRM.	Increase capability.	25%	45%
D	Add 2 batteries & solar array area	NONE	NONE	NONE	NONE	12%	7%
E	Add 1 battery & solar array area	Heavier wheels & torquers	NONE	Add 2 tanks. Add SRM.	Increase capability	31%	41%
SEOS	NONE	Heavier wheels & torquers	NONE	Add 1 tank	Increase capability	58%	35%
SEASAT A	Add 1 battery & solar array area	NONE	NONE	NONE	NONE	14%	4%
SMM	NONE	Heavier wheels & torquers	NONE	Add 1 tank	NONE	6%	32%

TABLE 15-4

COSTING METHODOLOGY UTILIZED IN STUDY

WBS NO.	ITEM	METHODOLOGY
1.0	EOS PROGRAM	
1.1	NASA PROG. MGMT	OMITTED
1.2	DMS	OMITTED
1.3	INSTRUMENTS	VENDOR DATA/ANALOGY
1.4	FLT OPS & SERV.	ENG. ESTIMATE
1.5	LAUNCH SYS	VENDOR DATA
1.6	SHUTTLE RESUPPLY PROJ.	PUBLISHED DATA
1.7	SPACECRAFT PROJECT	PARAMETRIC ESTIMATE
1.7.1	PROJ. MGMT.	BY FACTOR
1.7.2	SYS. ENG. & INT.	BY FACTOR
1.7.3	SPACECRAFT	PARAMETRIC ESTIMATE
1.7.4	S/C GSE	ENG. ESTIMATE
1.7.5	LOGISTICS SUPT.	ENG. ESTIMATE
1.7.6	FACILITIES	ENG. ESTIMATE
1.7.7	VEHICLE LEVEL TEST	PARAMETRIC ESTIMATE
1.7.8	S/C REFURB.	BY FACTOR

TABLE 15-5 SAMSO - INPUT REQUIREMENTS FOR THE UNMANNED SPACECRAFT COST MODEL

	NON-RECURRING (NR) COST DRIVERS	UNIT RECURRING (UR) COST DRIVERS
Dispenser	Weight per Spacecraft	Dispenser Weight
Structure, Thermal Control and Interstage	Subsystem Weight	Subsystem Weight
Propulsion	Total Impulse (lbs-sec)	N/A
Communications Primary	Subsystem Weight (X_1) Max Array Output (X_2)	Subsystem Weight
Secondary	Subsystem Weight	
TT&C	Subsystem Weight	Subsystem Weight
Combined Communications and TT&D	Combined Subsystem Weight	Combined Subsystem Weight
EPS	Max Array Output (watts)	Product of Wt. and Area
ACS	Subsystem Dry Weight (X_1) No. of Axis Stabilized (X_2)	Subsystem Dry Wt. (X_1) No. of Axis Stabilized (X_2)
Program Level	Other NR	Other UR
AGE	Analogous	N/A
Launch & Orbital Ops Support	N/A	Analogous

TABLE 15-6 SELECTION OF MULTIPLE MISSION SPACECRAFT

MULTIPLE MISSION SPACECRAFT	SUBSYSTEM: EPS WATTS	SUBSYSTEM: ACS DEGREES	SUBSYSTEM: CD&H MBS	SUBSYSTEM: STABILITY DEGREES/SEC	ACCOMPANYING SINGLE-MISSION SPACECRAFT	SPACECRAFT SUGGESTED FOR ANALYSIS
ACDF	455	.0014	435	$.46\times10^{-6}$	BEGH	
ACDFH					BEG	
ACDFG					BEH	
ACDEF					BGH	
ABCDF					EGH	
ABCDFG					EH	
ABCDGH					EF	
ACDEFG					BH	X
ACDEFH					BG	
ACDEGH					BE	
ABCDEF					GH	
ABCDEFGH					E	
ACDEFGH					B	
ABCDEFG					H	
ABCDEFH					G	
ABCDEFGH					NONE	X
ACDH	455	.0016	435	$.93\times10^{-6}$	BEFG	
ACDGH					BEF	
ACDEH					BEG	
ABCDH					EFG	
ABCDFH					EG	
ACDEGH					EF	
ABCDEH					EH	
ABCDEGH					F	X
ACF	450	.0014	435	$.46\times10^{-6}$	BDEGH	
ACFH					BDEG	
ACFG					BDEH	
ABCF					DEGH	
ACEI					DEG	
ABCFH					BDE	
ACFGH					DEIH	
ABCFG					DGH	
ABCEF					BDGH	
ACEFH					BDG	
ACEFG					BDH	
ACEFGH					BD	
ABCEFG					DH	
ABCEFH					DG	
ABCFGH					DE	
ABCEFGH					D	X
ACH	450	.0016	435	$.93\times10^{-6}$	BDEFG	
ACGH					BDEF	
ABCH					DEFG	
ABCH					DEFG	
ABCEH					BFG	
ABCGH					DEF	
ACE H					BDFG	
ACEGH					BDF	
ABCDGH					DF	
ACD	455	.01	435	1×10^{-6}	BEFGH	
ACDG					BEFH	
ABCD					EFGH	
ACDE					BFGH	
ACDEG					BFH	
ABCDG					EFH	
ABCDE					FGH	
ABCDEG					FH	X
AC	450	.01	435	1×10^{-6}	BDEFGH	
ACG					BDEFH	
ABC					DEFGH**	
ACE					BDFGH	
ACEG					BDFH	
ABCE					DFGH	
ABCG					DEFH	
ABCGH					DEF	
ABCEG					DFG	
ABDF	455	.0014	300	$.46\times10^{-6}$	CEGH	
ABDFH					CEG	
ABDFG					CEH	
ABDEF					CGH	
ABDFGHI					CE	
ABDEFH					CG	
ABDEFG					CH	
ABDEFGH					C	X
ABDH	455	.0016	300	$.93\times10^{-6}$	CEFG	
ABDEH					CFG	
ABDGH					CEF	
ABDEGH					CF	
ABD	455	.01	300	1×10^{-6}	CEFGH	
ABDE					CFGH	
ABDG					CEFH	
ABDEG					CF	X
ADEF	455	.0014	200	$.46\times10^{-6}$	BCGH	
ADEFH					BCG	
ADEFG					BCH	
ADEFGH					BC	X
ADEH	455	.0016	200	$.93\times10^{-6}$	BCFG	***
ADEGH					BCF	
ADE	455	.01	200	1×10^{-6}	BCFGH	
ADEG					BCFH	
ADF	455	.0014	150	$.46\times10^{-6}$	BCEGH	
ADFH					BCEG	
ADFG					BCEH	
ADFGH					BCE	
ADH	455	.0016	150	$.93\times10^{-6}$	BCEFG	
ADGH					BCEF	
ABFG	350	.0014	300	.46	CDEH	
ABFGH					CDE	
ABEFG					CDH	
ABEFGH					CD	
ABGH	350	.0016	300	.93	CDEF	
ABEGH					CDF	
ABG	350	.01	300	1×10^{-6}	CDEFH	
ABEG					CDFH	
ABF	200	.0014	300	.45	CDEGH	
ABFH					CDEG	
ABH	200	.0016	300	.93	CDEFG	
AH					BCDEFG	
AB	200	.01	300	10^{-6}	CDEFGH	
ABEFH	268	.0014	300	.46	CDG	
ABEF					CDGH	
ABEH	268	.0016	300	.93	CDFG	
ABE	268	.01	300	1×10^{-6}	CDFGH	
AEFG	350	.0014	200	.46	BCDH	
AEFGH					BCD	
AEGH	300	.0016	200	.93	BCDF	
AEG	350	.01	200	1×10^{-6}	BCDFH	
AEF	228	.0014	200	146	BCDGH	
AEH	228	.0016	200	.93	BCDFG	
AE	228	.01	200	1×10^{-6}	BCDFGH	
AFGH	200	.0014	150	.46	BCDE	
AF					BCDEGH	
AFG					BCDEH	
AFH	200	.0016	150	.93	BCDEG	
AGH					BCDEF	
AH					BCDEFG	
AG	350	.01	150	10^{-6}	BCDEFH	

NOTES:
1. GROUPS DIFFERING IN EPS POWER BY 5 WATTS (455W VS. 45W) COULD BE COMBINED.
2. X DENOTES SUGGESTED FOR ANALYSIS
3. ** DENOTES ANALYSIS COMPLETED
4. *** DENOTES CASES BELOW THIS POINT LIKELY TO HAVE CONTINUALLY INCREASING PROGRAM COSTS BECAUSE OF LARGE NUMBER OF SINGLE-MISSION SPACECRAFT

TABLE 15-7 SAMSO COST MODEL MATRIX

AREAS OF ACTIVITY / SUBDIVISION OF WORK	NON-RECURRING COSTS	RECURRING COSTS	TOTAL COSTS
1. Dispenser	X	X	X
2. Interstage	X	X	X
3. Spacecraft			
A. Spacecraft Level (Integration & Assembly)	X	X	X
B. Spacecraft Subsystems			
(1) Structure	X	X	X
(2) Thermal Control	X	X	X
(3) Propulsion	X	X	X
(4) Communications	X	X	X
(5) Telemetry, Tracking & Command	X	X	X
(6) Electrical Power	X	X	X
(7) Attitude Control	X	X	X
4. Flight Hardware Level	X	X	X
5. Aerospace Ground Equipment (AGE)	X	--	X
6. Launch & Orbital Operations Support (LOOS)			
7. Program Level (Not Subsystem Peculiar)			
A. Program Management	X	X	X
B. Systems Engineering	X	X	X
C. Systems Test & Evaluation	X	--	X
D. Acceptance Test	--	X	X
E. Data Management	X	X	X

TABLE 15-8 OUTPUT CATEGORIES SAMSO-UNMANNED SPACECRAFT COST MODEL

	NON REC.	REC.
o Structure, Thermal Control, and interstage	X	X
o Propulsion	X	X
o Communications	X	X
o Telem., Trking & Command	X	X
o Elec. Power Supply	X	X
o Attitude Control	X	X
o Program Level	X	X
o AGE	X	
o Launch & Orbital Operations support		X
o Burden & G&A	X	X
o Fee	X	X
o Spacecraft Program Total	X	

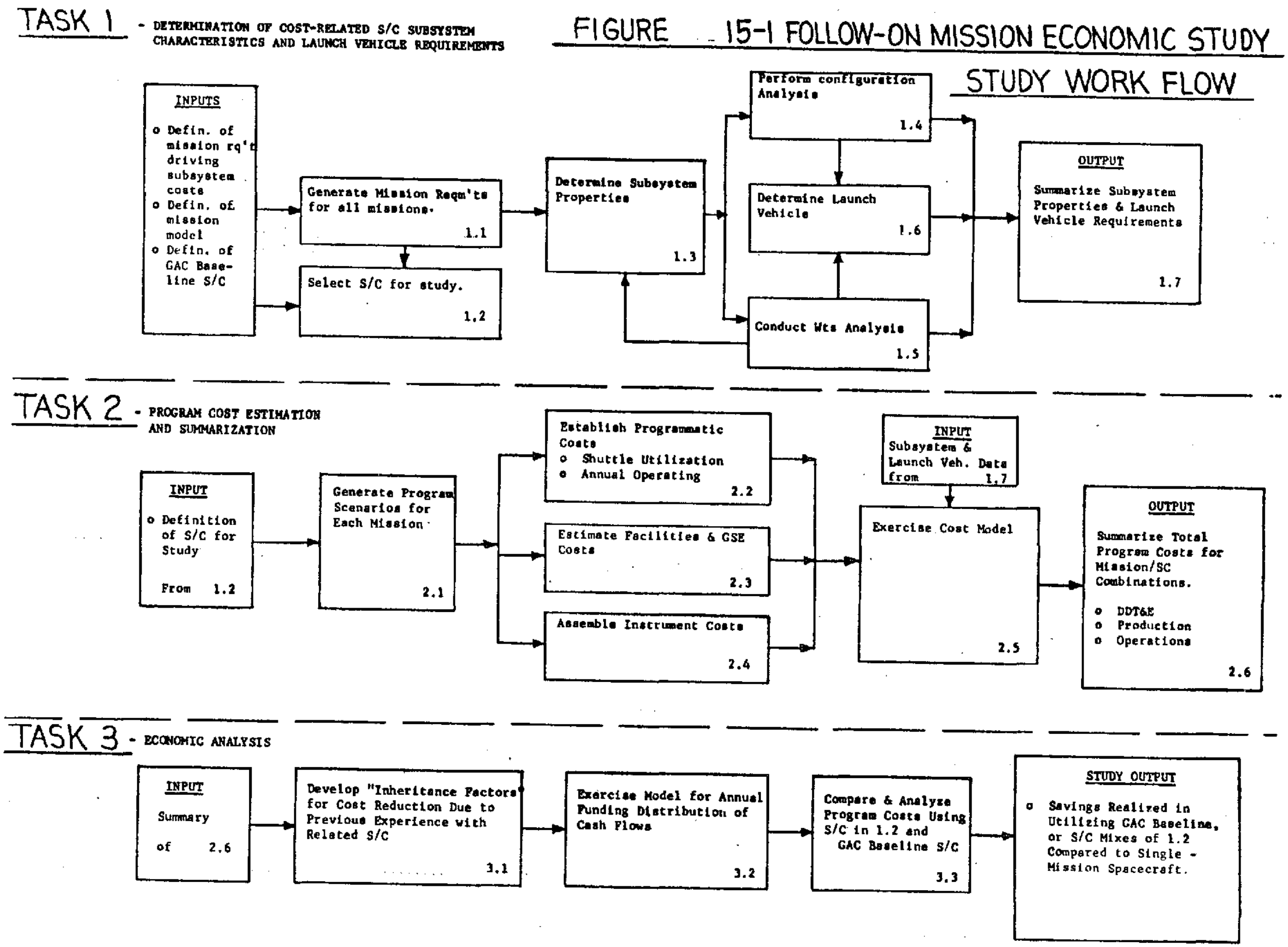

FIGURE 15-1 FOLLOW-ON MISSION ECONOMIC STUDY STUDY WORK FLOW

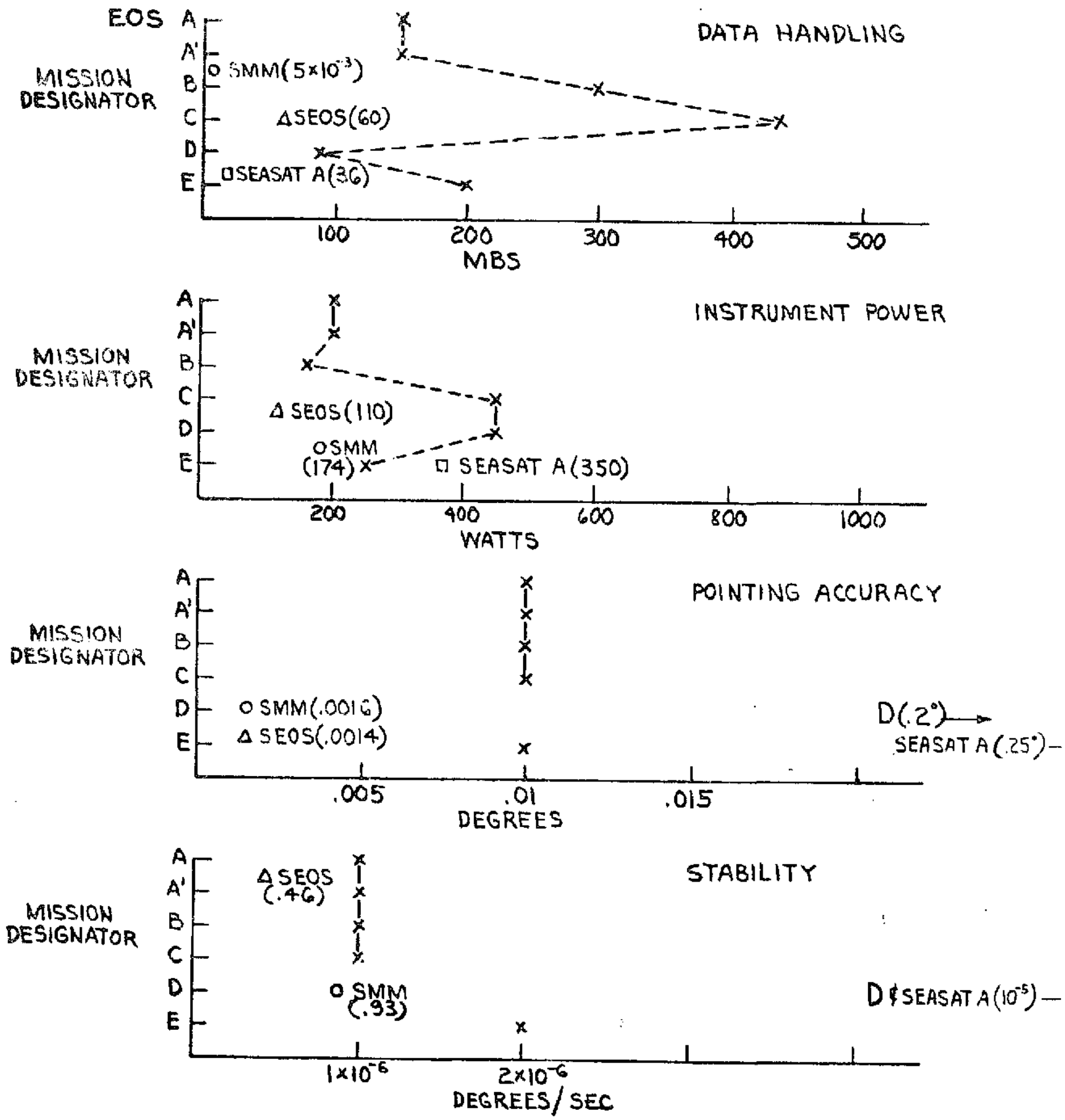

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Fig. 15-2 Subsystems Requirement Profiles

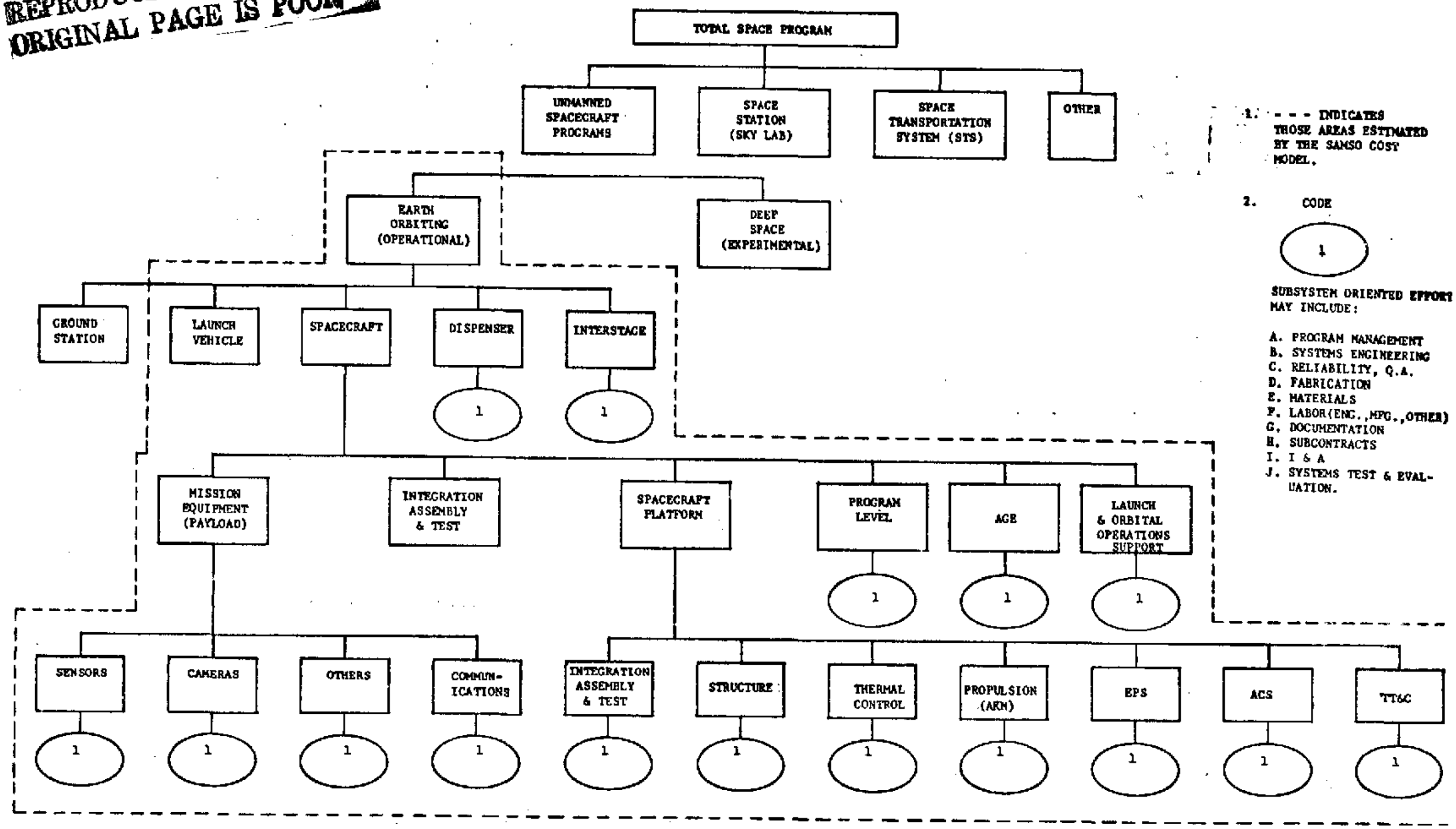

Fig. 15-3 Cost Elements for Samso Unmanned Spacecraft Cost Model

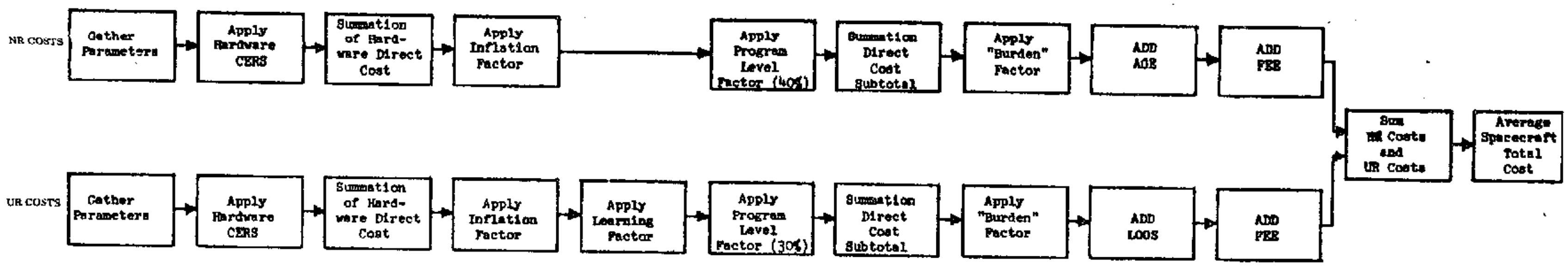

Fig. 15-4 Flowchart of a Typical Unmanned Spacecraft Cost Estimating Procedure

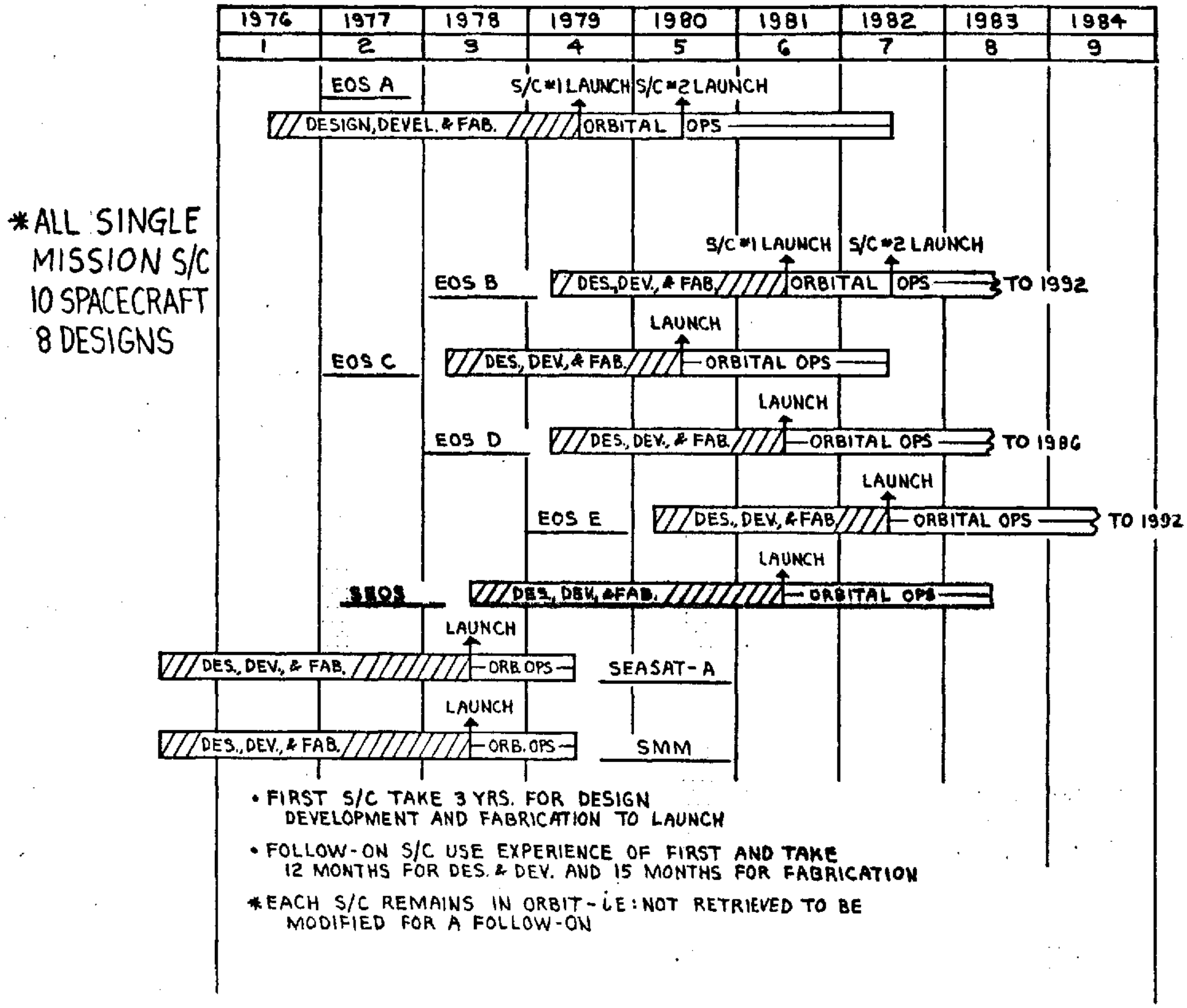

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Fig. 15-5 Program Scenario

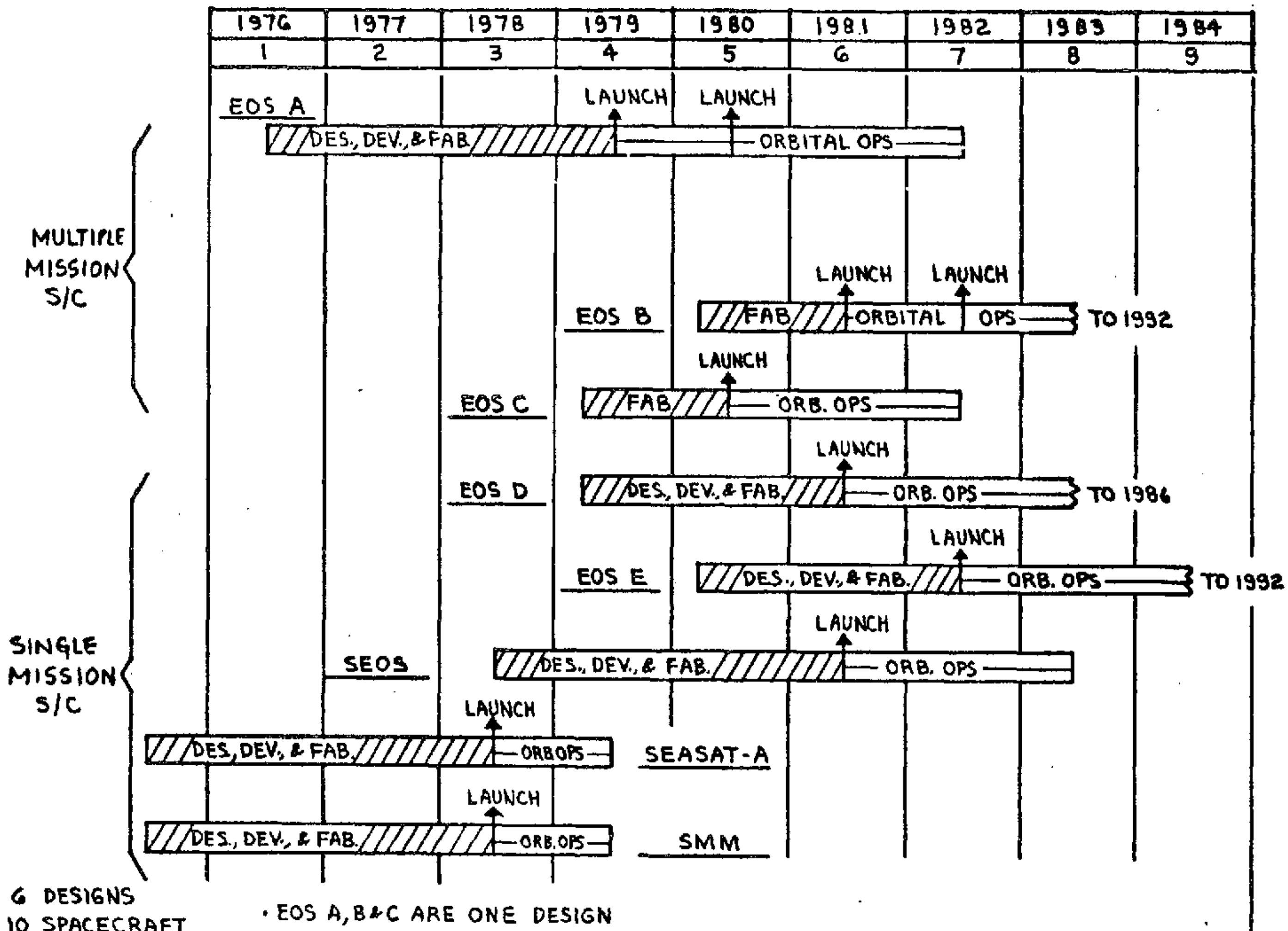

Fig. 15-5 Program Scenerio (cont)

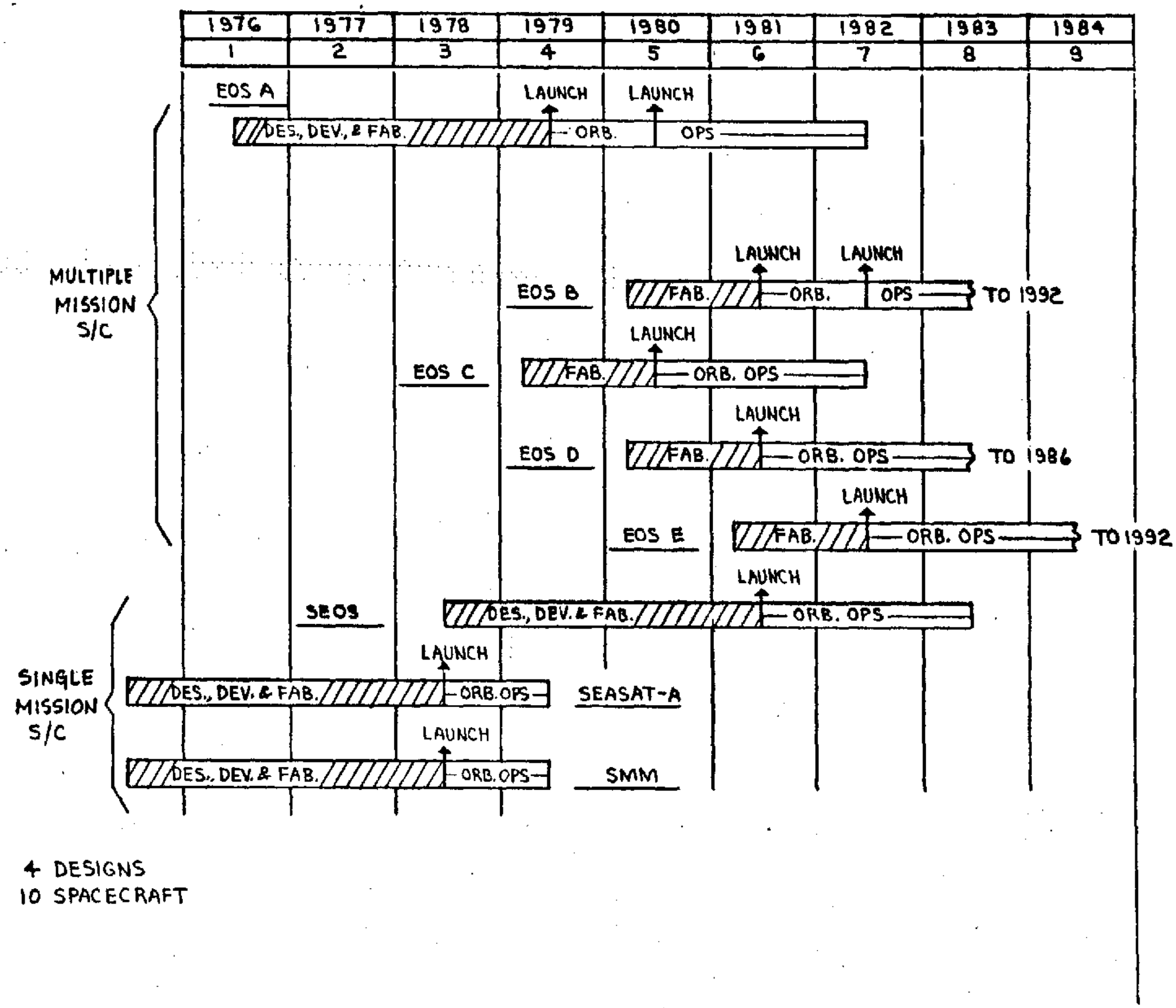

Fig. 15-5 Program Scenerio (cont)

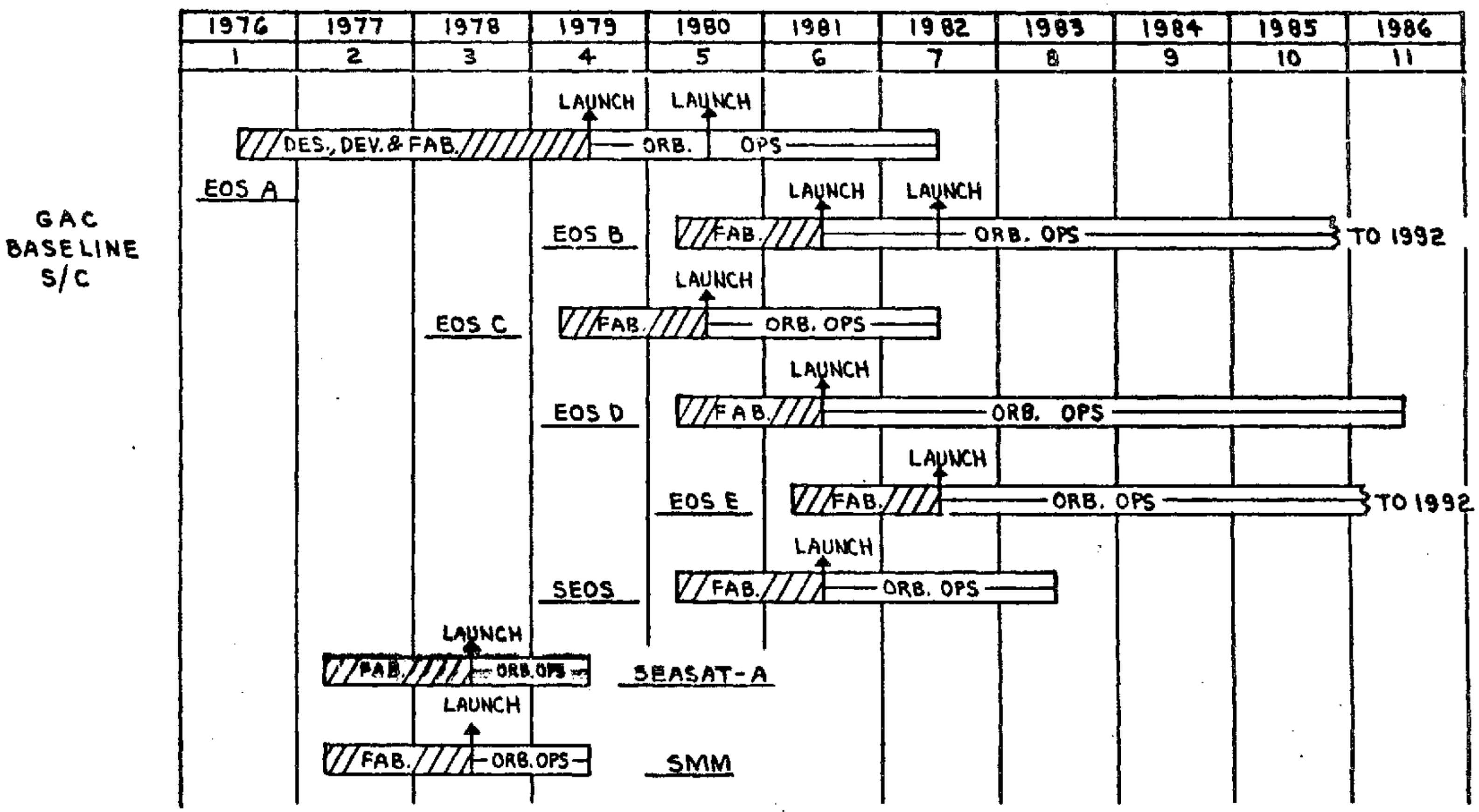

Fig. 15-5 Program Scenerio (cont)

SYSTEM TRADE
STUDY NO. 16

GRUMMAN

TRADE STUDY REPORT

TITLE	TRADE STUDY REPORT NO.
Single Satellite Versus Multiple Satellite	16
	WBS NUMBER

This study has developed as a result of our first phase effort. It will be conducted during the next phase and the results included in the final report.

See Report No. 3, <u>Design/Cost Trade-off Studies</u>, Section No. 6.16 for further information.

PREPARED BY	GROUP NUMBER & NAME	DATE	CHANGE LETTER
			REVISION DATE
APPROVED BY			PAGE 16-1

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SYSTEM TRADE
STUDY NO. 17

GRUMMAN AEROSPACE CORPORATION

TRADE STUDY REPORT

TITLE	TRADE STUDY REPORT NO. 17
Management Approach	WBS NUMBER

See Report No. 3, Section 6.17 and Report No. 4.

PREPARED BY	GROUP NUMBER & NAME	DATE	CHANGE LETTER
			REVISION DATE
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TRADE STUDY REPORT

TITLE	TRADE STUDY REPORT NO. 18
TEST PHILOSOPHY	WBS NUMBER

E-18 Test Philosophy

All Test Philosophy Trade Studies are documented in Section 3 of the Management Approach Report. (Report No. 4)

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			REVISION DATE
APPROVED BY			PAGE 18-1

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SYSTEM TRADE
STUDY NO. 19

GRUMMAN

TRADE STUDY REPORT

TITLE	TRADE STUDY REPORT NO.
RELIABILITY AND QUALITY ASSURANCE	19
	WBS NUMBER

See Report No. 3, Section 6.19

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